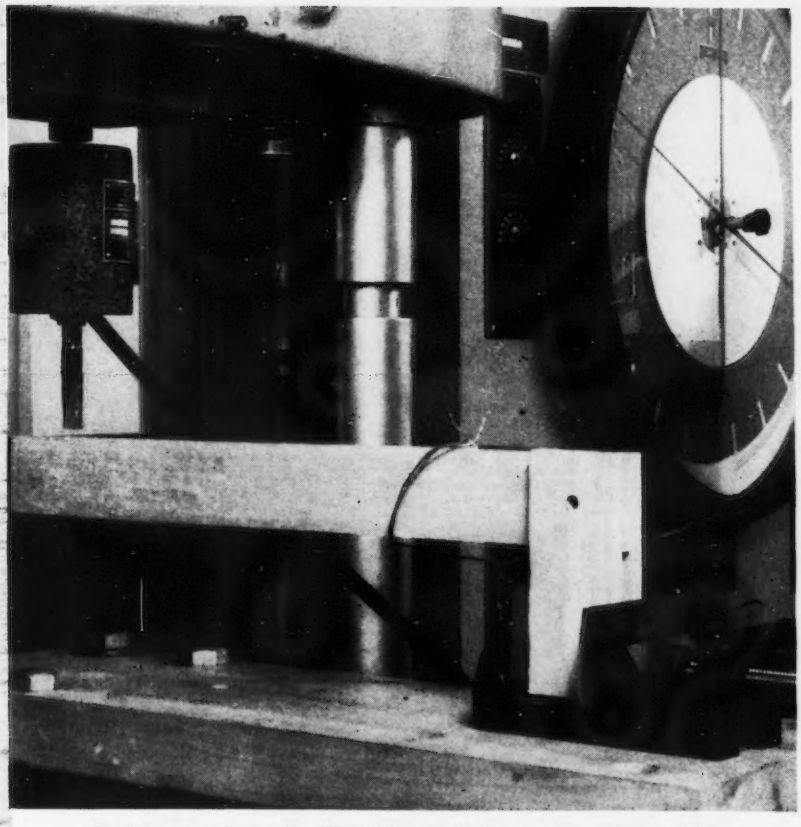
FOREST PRODUCTS JOURNAL

FOREST PRODUCTS RESEARCH SOCIETY

FPRS ANNUAL MEETING, JUNE 18-22, LOUISVILLE, KY.



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Annual Rings vs. Wood Quality of White Spruce

Preservative Action of Bound Copper and Zinc

Collapse in Wood

Statistics Make It Easy to Control Dry Kiln MC

Gamma Rays and Wood Density

Data-Handling Techniques for Particle Board

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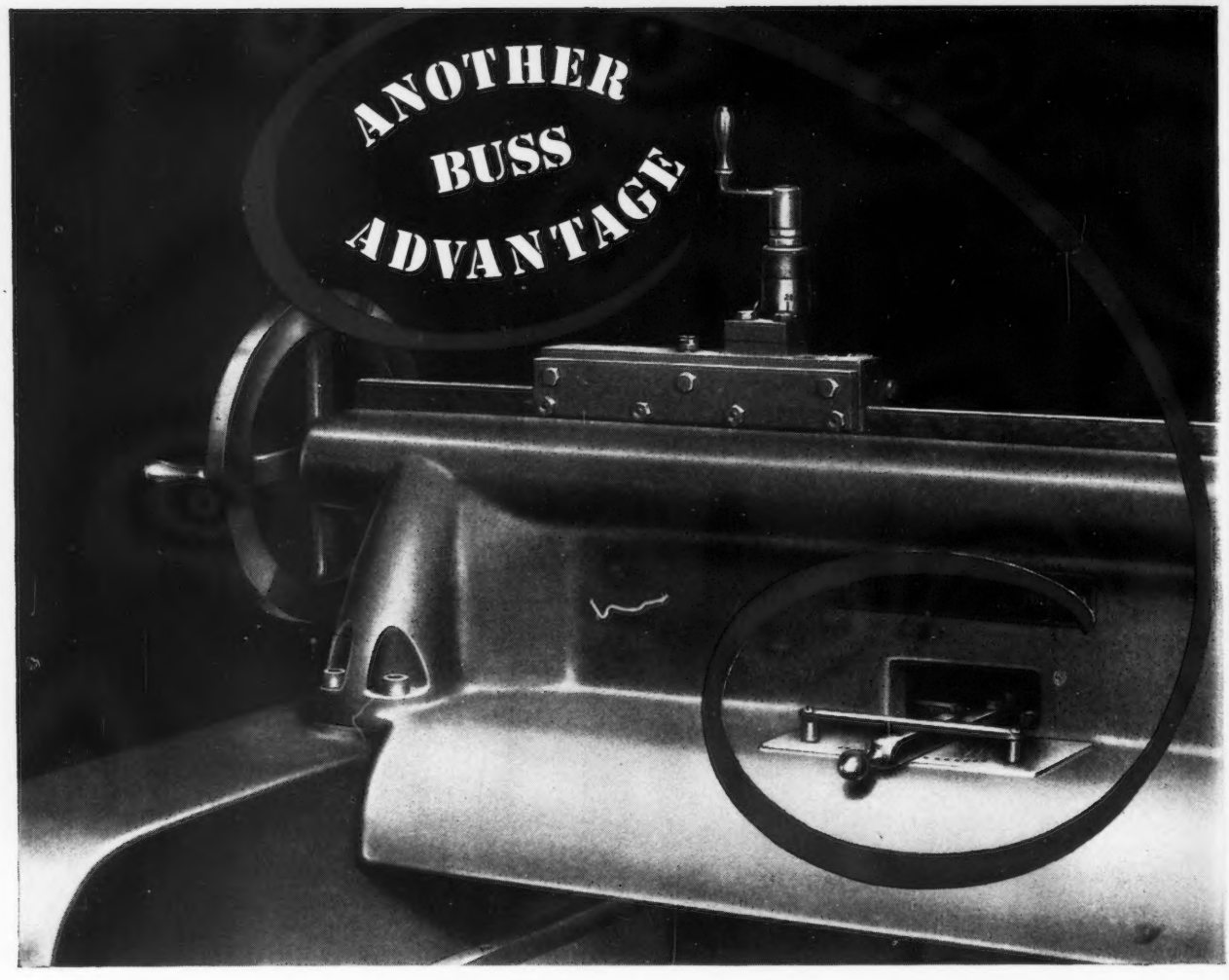

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THE FOREST PRODUCTS JOURNAL IS PUBLISHED MONTHLY BY THE FOREST PRODUCTS RESEARCH SOCIETY 417 NORTH WALNUT ST, MADISON 5, WIS. SECOND-CLASS POSTAGE PAID AT MADISON. ANNUAL SUBSCRIPTION RATE $20.00; SINGLE COPIES $1.50, EXCEPT OCTOBER YEARBOOK ISSUE, $4.00. THE SOCIETY IS NOT RESPONSIBLE FOR VIEWS EXPRESSED IN PUBLICATIONS.

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FPRS News-Digest

A Message from the President

. . . Raymond H. Berry

R. H. Berry

LAST JUNE, THE CONGRESS PASSED the Multiple Use Act which was based, essentially, on sound principles of forestry and land management. There was some opposition to this Act, not because of disagreement in principle but rather for fear of possible misinterpretation of the provisions of the Act. It was felt by some that governmental bureaus which conrolled its application could be subjected to political pressures to give preference to demands for "recreation" and "wild life" areas to the detriment of the development of the natural resources of wood and water and to the contravention of the genuine benefits of the doctrine of Multiple Use.

Today, however, we are faced with new legislative proposals in a diametrically opposite field. The Wilderness Bill (S. 14) is not dangerous because of possible misinterpretation in practice—it is basically harmful legislation in itself. The Bill now before the Senate Committee on Interior and Insular Affairs proposes that any "area of 5000 or more acres without roads" be automatically declared a Wilderness Area, to be locked away from not only access by the public (except for occasional hardy hikers) but from proper management of the land. Whipped up by clever propagandists for fish and game clubs and so-called "conservationists' who know little or nothing about successful land management, a demand is being created in the minds of voters to whom the word "wilderness" conjures up visions of Omar Khayyam's houri beneath the bough. Few of these voters ever expect to penetrate such a wilderness, but the romantic idea persists that it would be good for the nation to own a lot of wildernesses. There is no comprehension of the fact that land untouched by man is subject to natural depredators—fire, insects, bacteria, parasites, and animals—and that to lock it away in impenetrable blocks without roads defeats everything learned by land management experts in the control of such destruction.

There is no understanding, either, of the variation of types of land according to its optimum use. One of the most important contributions made by the Soil Conservation Service has been its classification of land. Of the eight classifications described, only one can possibly be completely relegated to wilderness, without need or use for management and ready access. Legislation that tends to seal up any of the other seven classifications of land does more than economic harm. It disturbs the balance of nature.

Yet, the Wilderness Bill makes no attempt to segregate wilderness areas that would encompass only those lands that fall in Class VIII. On the contrary, the Bill would include lands that *could* be in any classification. The only distinguishing mark would be that they consist of 5,000 or more acres without roads.

We who are engaged in the wood industry should be vocal and active in communicating to senators and representatives our opposition to such destructive procedures. Talk to your neighbors about the sweeping inaccuracy of the arguments being used to promote this bill, and sit down today and write your views to your congressman and senator. The past 50 years have taught man much about the preservation and reconditioning of his physical environment—let's not allow that knowledge to be drowned in a sea of uninformed public emotion.

STAFF MEMBERS Mary Sharkey and Claudette Ivey complete one-day mailing of FPRS Proceedings.

1947-51 FPRS Proceedings Hit "Best-Seller List"

The Executive Office is pleased to report that response to the special offer on FPRS Proceedings has been most gratifying. Orders are coming in daily from all parts of the United States and many other countries.

"We don't expect the 5-volume packet to replace the "book of the month, but membership response proves that the proceedings are a valuable reference tool for all phases of the forest products industry."

The special offer is still available. Complete sets will be mailed postpaid to any part of the United States for $3.00, anywhere else in the world for $5.00. See a complete description of the five volumes on the inside back cover, then use the convenient Reader Service Form to place your order.

Rocky Mountain Section Announces New Officers

Annual meeting of the Rocky Mountain Section was held February 1, 1961 in Denver, Colorado. Guest speaker for the dinner meeting was Dr. E. G. Locke, director of the U. S. Forest Products Laboratory, Madison, Wis.

The following were elected Section officer: Chairman, Robert Bader, Manufacturers Representative, Denver; Vice Chairman, Lincoln Mueller, Rocky Mountain Forest and Range Experiment Station, Colorado State University; Secretary-Treasurer, Philip M. Opsall, Jason Associates, Fort Collins; and Trustee, Harry E. Troxell, Colorado State University.

1961 Officers Announced For UMV Section

Results of the December balloting for the Upper Mississippi Valley Section have been tabulated an the Tellers Committee is happy to announce the names of the Section Officers for the calendar year 1961: Chairman, L. A. Ropella, Roddis Plywood Co., Marshfield, Wis.; Vice-Chairman, S. H. Wise, Wood Conversion Co., Cloquet, Minn.; Secretary, Richard Marden, Lakes States Forest Experiment Station, Schofield, Wis.; Treasurer, J. A. Pence, Weyerhaeuser Sales Co., St. Paul, Minn.; and Trustee H. R. Emerson, Chippewa Lumber Industries, Inc., Glidden, Wis.

See Reader Service Form, page 12-A

Wood Award Judges Named

Judges for the "Wood and Wood Products Award" will be Harry E. Troxell, Jr., School of Forestry, Colorado A & M College, Ft. Collins, Colo.; Dr. Hereford Garland, Forest Products Research Division, Michigan College of Mining & Technology, Houghton, Mich., and Dean Boyd Richards, Forestry Department, Alabama Polytechnic Institute, Auburn, Ala.

All entries should be submitted to the respective deans or heads of departments, who will, then, submit them by April 25 to the Executive Secretary of the Forest Products Research Society. The Secretary will transmit entries promptly to the Judging Committee. A short autobiography and photo of the author should accompany the paper. Papers should conform with FPRS style standards, consist of from 2,000 to 7,000 words, and be in triplicate. A short news-type abstract should accompany, but not be an integral part of, the paper. Judges will rate the essays on the basis of subject, skill of treatment, conclusions, and applicability.

In the event that a total number of less than five titles are received by April 1, 1961, no awards will be made. The judges reserve the right to cancel the Awards in the event that less than four final entries are submitted by April 25, 1961.

The winner of the $350 Award will be requested to present his paper at the Annual Meeting of the FPRS, June 18–22, at Louisville, Ky. The winner of the $150 Award may receive his award at the time of the National Meeting, although it is not a requisite that he attend the meeting. All papers will be considered for publication in the *Forest Products Journal*.

Rovsek Named "Wood" Managing Editor

Frank J. Rovsek, for 10 years executive secretary of FPRS, has joined the staff of WOOD & WOOD PRODUCTS as managing editor. Since his resignation from the society's chief administrative post, Rovsek had been associated with the American Hardboard Association.

Rovsek's extensive experience has included research, advertising and marketing work with Allis-Chalmers Mfg. Co. and Montgomery Ward & Co. as well as editorial work. He holds a degree in business administration from Marquette University, and is a member of Toastmasters International, FPRS, and other groups. He resides in Wilmette, Ill., with his wife Betty Jane and their four children.

CONVENTION HEADQUARTERS

Headquarters for the 15th Annual Meeting of FPRS will be the Kentucky Hotel, Louisville, Ky. Make your reservations now.

PACIFIC NORTHWEST SECTION OFFICERS at annual meeting 6 and 7 February 1961, in Portland, Oregon. Left to right: A. L. Bonutto, trustee; R. H. Ripley, treasurer; E. H. Clarke, chairman; Don Burnet, vice chairman; W. R. Francis, past chairman; R. W. Petterson, secretary; Tom McKenna, membership chairman; and E. D. Farley, local arrangement chairman for the meeting.

Ad Leader Gives Success Tips at Pacific Northwest Meeting

"Success of a new product can be predicted and chances of success can be increased by methods now known," stated T. N. Tracy, Vice President of McCann–Erickson Advertising Agency at the annual spring meeting of the Pacific Northwest Section in Portland, Oregon, February 6–7.

Speaking before more than 100 members and guests at the Section's banquet. Tracy described the sales life cycle of a product and the relationships of possible volumes, degree of competition, patent protection, tooling and marketing costs, and money available.

Information outlined by Tracy highlighted the two-day meeting in which some 150 attended technical sessions.

Technical Sessions

The first session included four talks on veneer and plywood. M. F. Bengelsdorf, Douglas Fir Plywood Association, Tacoma, Wash., described a study to compare veneer peeled from blocks chucked at the pith with that from blocks chucked at the geometric center. Fred H. Milligan, Development Engineer, Canadian Western Lumber Co., Fraser Mills, B.C., outlined rapid drying of veneer from western softwoods in the experimental drier operated at high temperatures. John Carstensen, Research Chemist, Monsanto Chemical Co., Seattle, Wash., reported on gluing charactertics of veneers from little-used western hardwoods and softwoods, and Rom Whyte, Development Engineer, Weyerhaeuser Co., Longview, Wash., compared half-inch plywood sheathing of 3-ply and 5-ply construction.

The second session consisted of two general talks on lumber and wood products and a panel discussion on hardboard and particle board.

Harold E. Worth, Technologist, Pacific Northwest Forest and Range Experiment Station, Portland, Ore., discussed the implications of structural lumber grading, and J. T. Hansen, Chief Architectural Examiner, Federal Housing Authority, Portland, Ore., told how Federal standards affect the use of wood products in construction.

Dr. George G. Marra, Washington State University, moderated the panel on standardization and certification of board products. Norman Briggs, Plant Manager, Weyerhaeuser Co., Klamath Falls, discussed problems of standardizing hardboard, and Ronald G. Frashour, Assisstant Superintendent, Pacific Plywood Company, Dillard spoke about possibilities with particle board.

Field Trips

Groups toured the world's largest specialty paper mill. Crown Zellerbach Corp., Camas, Wash., and viewed automatic, efficient equipment for materials handling at the new waterways terminal in Portland.

Section Officers

Officers of the Pacific Northwest Section for 1961 present at the spring meeting included Chairman E. H. Clarke, Pacific Northwest Forest and Range Experiment Station; Vice Chairman Don Burnet, Central Research Division, Crown Zellerbach Corporation, Camas, Wash., Secretary Richard W. Petterson, Director of Research, Saint Paul & Tacoma Lumber Company, Tacoma, Wash.; Treasurer Robert H. Ripley, Manager, Quality Control Division, Douglas Fir Plywood Association, Tacoma, Wash.; Membership Chairman Tom McKenna, Kirkland, Wash.; and Trustee A. L. Bonutto, Monsanto Chemical Co., Seattle, Wash.

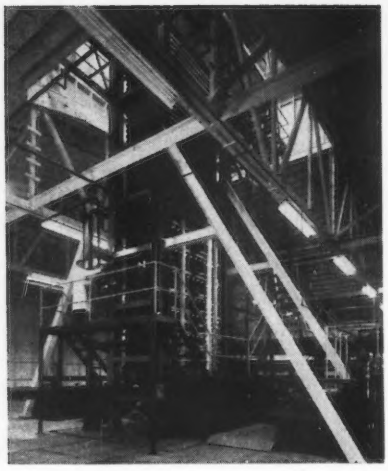
Next Meeting

The next meeting of the FPRS Pacific Northwest Section will be held in Medford, Oregon, May 8-9, according to Chairman E. H. Clarke, technologist at the pacific Northwest Forest and Range Experiment Station.

The two-day meeting will include technical sessions and field trips. It has been planned as a means of providing the latest results of research and enabling the industry to apply the information to commercial practice.

Clarke reports that membership interest indicate the meeting will draw a good representation of PNW members and guests from British Columbia, Washington, and Oregon.

 See Reader Service Form, page 12-A



Georgia Pacific Announces Continuous Plywood Process

The first continuous process for making plywood was announced recently by Georgia-Pacific Corporation.

Described as the "plywood of the future," the new product has been named Fiber-Ply. It will be produced at a new G–P plant in Springfield, Oregon. Initial production will be at the rate of 2,600,000 square feet a month on ⅜–inch basis. Fiber-Ply is expected to reach U.S. markets late in March.

"The new process eliminates many time-consuming and costly steps, and it produces a hard-surfaced panel with many new qualities. It will make plywood even more competitive in the worlds building materials markets," said R. B. Pamplin, G–P president.

The process is centered around a new type hot press, said by G–P to be the largest plywood press in the world (see above). Fir veneers and resin-impregnated wood fibers are permanently bonded in the 60-opening press in one continuous operation.

Developed by G–P research teams, the process reverses the traditional method of plywood manufacturer. Green veneers move directly rfom the log into the 4-story press where they are heat-pressed with dry glue and outside layers of resin impregnated kraft pulp into permanently bonded and dry panels ready for shipment.

Fiber-Ply has 5 plys instead of the 3 plys found in conventional plywood of ⅜ inch thickness. They include 2 plys of resin-impregnated fiber and 3 plys of veneer. In the ½, ⅝ and ¾ inch thickness, 7 plys are used.

The material has been tested for use anywhere conventional interior or exterior fir plywood is used. Both exterior and interior grades are being manufactured. Current test runs have proved highly successful, and full production will start in March.

In announcing the new process Pamplin said, "We expect this break-through in forest products manufacture to open many new markets on the basis of both highly competitive cost and new qualities."

The process has been fully patented, and production and distribution will be controlled exclusively by Georgia-Pacific.

New Wood Pulping Process

University of California chemists announce substantial progress toward the achievement of an economically feasible chemical wood pulping process for their state. The new process uses nitric acid and ammonium hydroxide in a two-stage operation to make pulps from wood chips, sawdust, and other residues, and converts most of the effluents or wastes into introgen fertilizer. Thus, it appears capable of hurdling the major obstacles that have limited the developemnt of the wood pulping industry, California's strict specifications for water usage and her great concern over possible stream pollution from wastes of conventional pulping industries.

Dr. D. L. Brink, member of a team composed to overcome the problem, reports that under certain conditions losses have been cut to a commercially acceptable level and that up to 80% of the nitric acid can be recovered as nitrogen for use in the production of fertilizers or as oxidizable oxides of nitrogen which can be reconverted to nitric acid and used again.

Wooden Pallet Industry Sets All-Time Record

The wooden pallet industry set a new all-time production and sales record during 1960, according to reports from the 14th Semi-Annual Meeting of the National Wooden Pallet Manufacturers Association, which recently concluded in Litchfield Park, Ariz.

Last year's sales in the wooden pallet industry were estimated at approximately $162,811,000, which represented an 8.8 percent increase over 1959 expressed in dollar volume. The previous record year for the wooden pallet industry was 1959 when a $149,203,000 volume was experienced. NWPMA predicts that production for 1961 will be around last year's figure, and that the wooden pallet industry will hold its own despite the recession. "It is even possible that this industry may register modest new production and sales gains in 1961," said NWPMA Executive Vice President William H. Sardo, Jr.

The convention approved the largest Trade Promotion program ever for NWPMA during 1961, and a 5.8 per cent increase in the budget to finance the stepped-up pallet industry effort.

U. of Washington Awards Research Grants

The University of Washington Institute of Forest Products has recently presented several research awards as part of its program to stimulate and actively sponsor research work which deals with problems related to forest products.

The recipients of the graduate student research assistantship awards are: Jozsef Bodig, R. W. Braue, E. M. Estep, R. S. Gaudette, C. E. Ludwig, and R. C. Woodfin, Jr. P. E. Heilman was awarded a prodoctoral research grant.

A grant has also been made to Professor Ben S. Bryant to aid in his research on "The Effect of Post-Treatments of Raw Wood Pulps for Paper Making."

College of Forestry at NY State U to Celebrate Golden Anniversary

The College of Forestry at the State University of New York will celebrate its Golden Anniversary, April 12–14, at Syracuse.

Nationally and internationally known leaders in the fields of forestry and the forest products industry will attend the three-day program.

Registration at 9:00 a.m., Wednesday April 12 at Bray Hall Rotunda, will begin a day highlighted with such events as an open-house exhibit in all college departments and the dedication of the H. P. Brown Memorial Wood Collection. After a reception for alumni and guests from 4-5 p.m. in Marshall Lounge, the day will conclude with class reunion dinners at 7 p.m.

A general session on the challenges of forestry, forest land use, use of wood, and forestry education will be held on Thursday morning April 13. The session will be opened by the chairman, J. E. McCaffrey, vice president, International Paper Co.; other guest speakers will include R. E. McArdle, chief, U.S. Forest Service; H. Morgan, vice president, Weyerhaeuser Co.; and H. Vaux, dean of the school of forestry, University of California.

Four concurrent technical symposia will be held in the afternoon. Session A, on forest resources, will be headed by C. L. Wirth, director, National Park Service and will include as speakers: L. Rockefeller, chairman, Outdoor Recreation Review Committee. W. A. Duerr, chairman, Department of Forestry Economics, State University College of Forestry; H. G. Wilm, commissioner, New York Conservation Department; and J. Buckley, director Patuxant Wildlife Research Center, U.S. Fish and Wildlife Service. Session B, dealing with forest production and headed by P. A. Briegleb, director, Southern Forest and Range Experiment Station, U. S. Forest Service, will feature as speakers: Prof. T. P. Kozlowski, Department of Forestry and Wildlife Management, University of Wisconsin; L. S. Minckler, research forester, Central States Forest Service; Prof. D. P. White, Department of Forestry, Michigan State University; and T. W. Earle, vice president in charge of the Woodlands Division, Continental Can Company. E. Harrar, dean, School of Forestry, Duke University, is chairman of Session C, which is concerned with new uses for wood. The speakers are J. S. Bethel, head, Special Projects in Science Education, N.S.F.; H. B. McKean, director of research, Potlatch Forests, Inc., and A. Lahey, assistant to the manager, Product Planning Department, Weyerhaeuser Company.

The final symposium, on research, will have H. F. Lewis, vice president, of the Institute of Paper Chemistry as chairman. Speakers are F. T. Peterson, president of Black-Clawson Company; J. McCarthy, dean of the graduate school, University of Washington; and H. Mark, director of the Polymer Research Institute of Brooklyn.

The official banquet will be held Thursday evening at the Hotel Syracuse, and the entire celebration will conclude with the conferring of honorary degrees and alumni awards on Friday.

See Reader Service Form, page 12-A

Mexico Companies Form Adhesives Association

The following companies have formed the National Association of Adhesive Manufacturers of Mexico, under the name of Association Nacional de Fabricantes de Pegamento, A.C.:

Adhesivos Resistol, Casco Quimica De Mexico, Industrial Barsic, Minnesota Manufacturera de Mexico, Pegmentos Y Apresto, Productos Barge, Productos Especializados de Hule, Productos Flexo, Productos Industriales El Leon, National Starch and Chemical De Mexico, Tecnica Industrial Asbun, and United Productos Industriales.

Objective of the new association, according to President Rodolfo Patron of Adhesivos Resistol, is organize all responsible manufacturers of adhesives in Mexico to serve as a consulting body on the adhesive markets, to advise the consumer as to what products are made in Mexico, and to disseminate information on the adhesives industry. Headquarters will be in Mexico City.

Oregon State Develops Promising Herbicides

Dr. G. Harnes, assistant director of the Oregon State College forest research division, and M. Newton, research forester, report that research with chemical controls by the school of forestry shows promise for reducing the future loss of product capacity of more than 60% of forest lands of western Oregon. Results obtained with recently developed herbicides indicate that control of vine maple and bigleaf maple may become possible on an economic basis. Improved controls for snowbrush, madrone, and elderberry also have been developed in the studies. Adequate controls for poison oak and blackberry, have not yet been found, however.

Further study of tree psysiology, metabolism, and, translocation should eventually lead to methods of treating large trees aerially on a practical basis, Barnes and Newton believe. They forsee the day when brush fields can be completely controlled by a single spray application.

School Fire Report Ready

The report titled "School Fires: An Approach To Life Safety" is now off the presses and available. Carried out under the auspices of the Building Research Advisory Board—an operating unit of the National Academy of Science's Division of Engineering and Industrial Research—in concert with the Committee on Fire Research, and supported by a grant from the Educational Facilities Laboratories, Inc., it represents a compilation of data and informed opinions on a subject made vivid for the American public by the 1958 disaster at Our Lady of the Angels School in Chicago.

The report, profusely illustrated with drawings and photographs, may be obtained at a single-copy price of $2.50 (with special prices on multiple-copy orders) from the Printing and Publishing Office of the National Academy of Sciences–National Research Council, 2101 Constitution Avenue, N. W., Washington 25, D. C.

COMING EVENTS

Apr. 5–7: Annual meeting, Southern Pine Assn., Roosevelt Hotel, New Orleans, La.

★

Apr. 6–7: Tenth Annual Forestry Symposium, Louisiana State University, Baton Rouge, La.

★

April 7–9: Southern Pine Machinery and Equipment Exposition, Municipal Auditorium, New Orleans, La.

★

Apr. 10–12: ASTM Committee D-10 on Shipping Containers, American Society For Testing Materials, Chicago, Ill.

★

Apr. 10–21: Kiln Drying Demonstration, U. S. Forest Products Laboratory, Madison, Wis.

★

Apr. 11–12: Joint FRPS Inland Empire Section and Northwest Wood Products Clinic, Davenport Hotel, Spokane, Wash.

★

Apr. 12–14: Fiftieth anniversary celebration, State University, College of Forestry, Syracuse University, Syracuse, N. Y.

★

Apr. 13–14: Canadian Wood Development Council, Beacon Arms Hotel, Ottawa, Ca.

★

Apr. 20–21: Annual Convention, National Association of Store Fixture Manufacturers, Drake Hotel, Chicago, Ill.

★

Apr. 24–28: University of California, 13th annual forestry field school, Placerville, Calif.

★

Apr. 30–May 3: Semi-annual meeting, National Retail Lumber Dealers Assn., Shoreham Hotel, Washington, D. C.

★

May 4–5: Spring meeting, Southern Woodwork Assn., Grand Hotel, Point Clear, Ala.

★

May 8–9: Spring meeting, FPRS Pacific Northwest Section, Medford, Ore.

★

May 11–13: Seminar, Wood Office Furniture Institute, North Carolina State College, Raleigh, N. C.

★

May 15–19: Annual meeting, American Institute of Timber Construction, Desert Inn Hotel, Las Vegas, Nev.

★

May 17–19: Transportation conference, National Association of Furniture Manufacturers, Purdue University, Ind.

★

May 18–20: Annual woodworking machinery exhibition, General Equipment, Inc., Statesville, N. C.

★

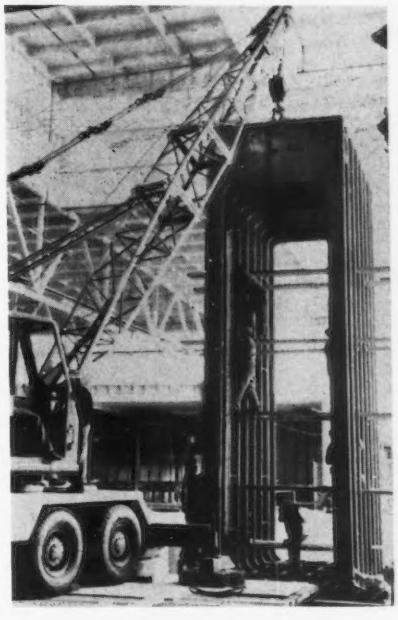
June 18–22: Annual Meeting, Forest Products Research Society, Kentucky Hotel, Louisville, Ky.

Wood Seasoning Clinic Planned

A joint wood seasoning clinic will be held in Grand Rapids May 18 and 19. Participating will be the West Michigan Wood Seasoning Clinic, the Midwest Wood Seasoning Association and the Grand Rapids Wood Seasoning Group.

The program, now being planned, will be a fast-paced exchange of ideas between dry kiln operators from Wisconsin, Minnesota, Iowa, Illinois, Indiana and Michigan, says program chairman E. M. Conway.

"The idea is to swap experiences on any phase of wood seasoning," Conway explains. We can all learn much from others in the same field, and this exchange of ideas will be supplemented as needed by the knowledge and opinions of three or four of the nation's top wood seasoning authorities". Conway, who is chairman of the Grand Rapids Wood Seasoning Group, is president of the lumber Drying Specialty Co. in Grand Rapids.



New Plant Doubles U.S.P. Particle Board Output

The largest wood particle board plant east of the Mississippi began operation recently in South Boston, Va., according to Gene C. Brewer, president, United States Plywood Corporation.

Geared to achieve an annual production of 30 million square feet of ¾ inch Novoply, the company's patented particle flake board, the new multi-million dollar U. S. Plywood facility has been under construction since July, 1959. Mechanical Giant (above) installed at the new plant is the 20-panel frame for what is believed to be the largest wood particle board press in the world.

Combined production of the new plant and the company's facility in Anderson, California, producing 50 million square feet of ¾" board annually, will make U. S. Plywood the largest manufacturer of wood particle board in the world, Mr. Brewer reported.

 See Reader Service Form, page 12-A

FACING THE FORCE OF THE HURRICANE without damage, this modern house, the home of Mr. and Mrs. R. S. Barrows, was 6 weeks old when the storm struck. All wood, except for the roof, the house is framed in 10-inch creosote-treated poles anchored to a concrete footing.

200 MILE WINDS AND 12 FOOT WAVES swept over this unfinished frame house, but the only damage was a small patch of felt blown off the roof. The house stands on 12-foot concrete columns and is framed with 2 x 4s, with the 1 x 6 storm sheathing applied diagonally.

Wood Constructed Buildings Best Withstand Hurricane

Wood has always endured best as a building material, says Ray Knopp, member of the engineering and advisory committee of the Southern Building Code Congress, after witnessing the destruction Hurricane Donna's 11-foot waves and 180 m.p.h. winds brought to the Florida Keys last September. In some cases, he said, buildings constructed from other materials and surpassing all building code requirements were completely destroyed, while a wood frame building next door remained intact, with little or no damage.

Supporting Mr. Knopp's attitude towards wood construction was William Baggs, editor of the Miami News. In an open letter to the governor of Florida, Mr. Baggs expressed his conviction that to him there was some meaning in the fact that wood buildings, some of them quite old, remained sound after years of exposure to storms while " . . . so many new homes and stores (were) gutted, smashed, and in pretty much of a total ruin."

Old Buildings

Some of the old buildings editor Baggs referred to are the board-and-batten structures put up fifty years ago by Henry Flagler for his railroad crews on Pigeon Key, a tiny speck of land under the Seven-Mile Bridge. The 130-year-old house where John Audubon lived and painted his Key birds has actually withstood dozens of hurricanes in its time. Of course, it was built to last for centuries—with 6 x 6-inch foundation timbers; 12 x 12-inch sills; 4 x 12-inch floor joists; 4 x 6-inch rafters; 4 x 4 and 4 x 6-inch studs. Like many other wood structures in the city, it has weathered countless gales and hurricanes, since Key West is one of the cities most frequently struck by destructive tropical storms.

Modern Home

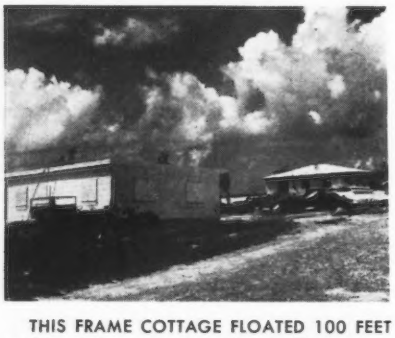
But modern wood houses also survived the 200-mile-an-hour winds of Hurricane Donna remarkably well. One example is the newly completed home of Mr. and Mrs. R. S. Barrows, which is all wood except for the roof covering. This house, which was designed by Robert B. Browne of Miami, is on a point of land reaching into the Atlantic at Marathon Shores, right in the heart of the most devastated area.

Framed in 10-inch creosote-treated poles, anchored to a concrete footing, the Barrows house, closest thing to a rigid wood tent, came through Hurricane Donna better than even the architect and builder had dreamed. Hundreds of concrete block houses literally blew apart when the storm swept up from the Florida Straits. But the Barrows house, its posts anchored to the coral rock that juts into the Atlantic Ocean, let the howling wind breathe through the great banks of wood louvered doors.

Designed For Survival

Why did the Barrows home stand up to Donna? First came the design that is similar to the old, wood Florida houses that were instinctively right for this tropical climate: a great overhanging roof to protect against the hot sun and driving rainstorms; the floor raised for additional storm protection and to allow freer air circulation.

When the water broke over the coral rock fill of the ocean front lot, it swept under the house. Maybe the 10-inch-diameter pine posts moved some, but there was an inherent strength and flexibility. These posts are strapped to the pad footings. There is excellent lateral stability. At the floor line and at the roof, paired 2 x 12-inch beams are bolted to the posts. These are tied to move as a whole.



THIS FRAME COTTAGE FLOATED 100 FEET and landed on a truck and rock pile, yet the building is not out of plumb or square at all—the doors still swing freely. The concrete slab next door collapsed after being deposited on the truck and rocks.

Minn. Timber Resources Studied by Forest Service

The U.S. Forest Service has begun a resurvey of the timber resources in southern Minnesota counties, according to M. B. Dickerman, Director of the Lake States Forest Experiment Station in St. Paul.

Inventories of forests in the northern part of the State have been under way for several months. Fieldwork in these areas is being done by the Office of Iron Range Resources and Rehabilitation, the Minnesota Department of Conservation, the Chippewa National Forest, and the U.S. Bureau of Indian Affairs. The Lake States Station and the Office of Iron Range Resources & Rehabilitation provide coordination in planning the surveys and combining the results so that reliable figures can be compiled for the State. In commenting on the new timber survey Dickerman stated, "An up-to-date appraisal of Minnesota's rapidly changing timber resource is needed by forest industries, private forest landowners and managers, and public agencies, in planning forestry programs and industrial development."

Dickinson Heads SWST Program

Dr. Fred Dickinson, director of the University of California's Forest Products Laboratory at Richmond, has been appointed head of the Society of Wood Science and Technology's visiting scientist program. Under the program, outstanding wood scientists will be brought to some 40 university and college campuses in the United States during the next 3 years to meet with faculty and students interested in this field of work.

The Executive Board of the Society also has named Dickinson a member of an 8-man steering committee which will guide a study of education in wood science and technology to be made in the next 2 years. Both projects will be financed with grants from the National Science Foundation.

Chapman, Homelite Awards Given Forestry Students

Five forestry students at the University of Minnesota have been named to receive Chapman Foundation Scholarships for 1960–61. The announcement was made jointly by A. Dale Chapman, president of the Chapman Chemical Company, Memphis, Tennessee, and F. H. Kaufert, director of the University's School of Forestry.

Awarded the $300 Chapman Foundation Scholarship for Freshmen Foresters is Paul Ochocki, Osseo, Minn. Recipients of the $2000 Chapman Foundation Scholarships for Sophomore Foresters are Richard Volk, St. Paul; Richard Klukas, St. Paul; Richard Lea, Minneapolis; and Larry Christian, Waltham, Minn.

Harrison Morton, St. Paul, and Richard Hilliker, Madison, University of Minnesota forestry seniors, have been named to receive $250 Homelite Scholarships.

See Reader Service Form, page 12-A

NEW PRODUCTS *and Literature*

New Chemical Controls Sap Stain and Mold

Wood Treating Chemicals, Company, St. Louis, Missouri, has announced that its previous product Noxtane now contains 40 percent technical sodium pentachlorophenate and 60 percent borax and dedusting agent. Called Super Noxtane, the new formulation represents an increase in sodium pentachlorophenate content from 33 percent to 40 percent—an increase that will provide substantially more effective control of sap stain and mold in newly sawn lumber.

The increase potency of Super Noxtane makes it identical to a formulation recommended by the U.S. Forest Service. In Technical Bulletin No. 1046, forest service experts state that, "When both effectiveness and bulk are considered, the commercial product containing sodium pentachlorophenate 1/2 plus borax 3/16 appeared to be the most efficient mixture of this type." U.S.D.A. tests indicate that Super Noxtane is almost as effective in the control of stain as straight technical sodium pentachlorophenate at full strength. For more information, including an illustrated brochure,

Circle Item 1

New Insulation Board

Simplex Paper Corp. of Adrian, Michigan, has taken advantage of a "built-in billboard" in marketing its new insulation board, "Thermo-ply." The aluminum-lined laminated fiberboard, incorporating thermal insulation with structural sheathing, is manufactured in 4 by 8 and 4 by 9-foot sheets. Packages for this large rectangular shape offer traveling billboards for prestige brand identification.

The system, developed by Bemis Bro. Bag Company, basically consists of equipment which accumulates a designated number of Thermo-ply sheets and softly ramloads them into a reinforced, form-fitting bag.

In addition to provide billboard advertising, the pre-printed bag is sturdier and more handsome than a handwrapped package. The packaging system also required about 50 per cent less work space and one-quarter the number of workmen than would have been required for handwrapping.

Circle Item 2

Victory Handbook Features Carbide Tipped Blades

With the ever increasing use of carbide tipped saw blades and tools, Victory Carbide Saw and Tool Company, Antioch, Ill., has just made available a book that combines the utility of a catalog and the function of a reference handbook.

The new book lists the most complete line of Carbide Tipped Blades and Tools available from one source. All of the standard blades such as the rip, cross-cut, thin-rim and hollow ground are listed. In addition, such exclusive Victory Blades as the M–20 Metal Cutting Blade, the BT–45 All Purpose, 3 and 1 Trim and the remarkable PC Penta-Cut Blades are also shown. Each blade is represented by accurate drawings of top, face and side tooth design—every possible specification is given. In all there are 14 different types of blades.

Circle Item 3

Vanply's Fiber-Tite

Fiber-Tite is the brand name of a particle board underlayment available exclusively through Vancouver Plywood Company. It is manufactured by Valley Wood Products, Inc. at Sweet Home, Ore.

The board is produced from Douglas-fir chips bonded together with moisture-resistant resins under heat and pressure. It is a strong, attractive panel of uniform density, dimensional stability and easy workability.

Although Fiber-Tite is specifically designed as floor underlayment, additional applications include furniture manufacture, sink and counter tops, cabinet and wardrobe doors and decorative wall coverings.

Circle Item 4

Gisholt Catalog Covers Masterglas Delwood

Gisholt Plastics, Madison, Wis. announces the availability of a new catalog covering Masterglas molded plastics and Delwood, a new wood-chip material.

Delwood is a formulation of cured wood chips, glass fibers, and waterproof resins. The result of 5 years of research, it is now being used in the furniture industry and wherever there is a further need for a contoured, medium density, molded core at a cost considerably below that of traditionally shaped products or components.

Circle Item 5

New Carborundum Catalogs

"Catalog of National Standard Abrasive Belts, Rolls, Sheets and Discs," by Carborundum's Coated Abrasive Division, lists standard coated abrasive products used throughout industry.

"Wide Belt Finishing," a new folder by Carborundum recites case study results where use of wide belts and wide belt machines for both wood and metal working cuts costs and expedites production while maintaining quality.

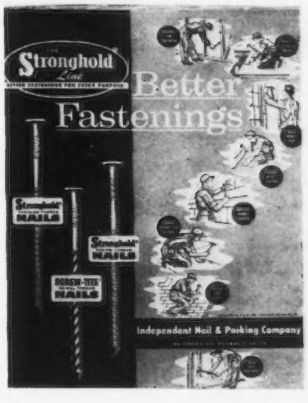
Circle Item 6

Weyerhaeuser Brochure Describes Versabord

The Weyerhaeuser Company's Silvatek Division has developed for the building trades a new 4 page brochure describing the versatility of Versabord—an all wood panel product used extensively as underlayment in floors and counter tops and as cabinet parts, shelving, closet doors, and wall paneling. Versabord meets all of the use requirements of these applications because of the engineered properties detailed in the brochure.

Also outlined in detail are instructions and recommendations for installing Versabord underlayment in the floor system. This product information is essential to insure 100 percent performance and satisfaction as covered by Weyerhaeuser's floor Underlayment Performance Guarantee.

Circle Item 7



New Nail Catalog Out

A new catalog covering the complete "Stronghold Line" of improved nails used in the building industry has just been issued by Independent Nail & Packing Company, Bridgewater, Mass. The company was the pioneer developer and is the world's largest manufacturer of nails made with scientifically engineered threads which result in a very substantial increase in holding power. This increased holding power permits many of today's cost-saving techniques in construction and often provides greater strength of fastening with shorter nails, slimmer nails and fewer nails, and with savings in time, labor and fastener cost.

For a copy of the new "Stronghold Line" Catalog write Independent Nail & Packing Company, Bridgewater, Mass.

The results of recent research carried on at the U. S. Forest Products Laboratory here are contained in 8 new reports now available for general distribution.

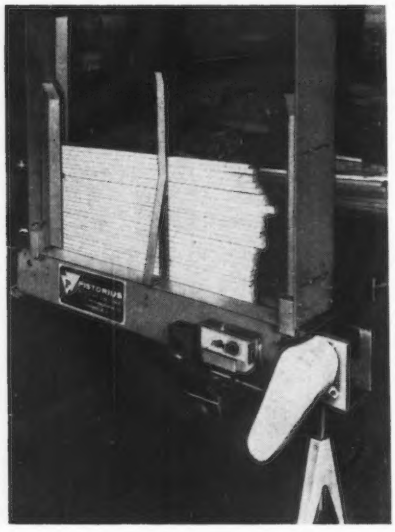
Circle Item 8

 See Reader Service Form, page 12-A

Pioneer Chain Saws

Pioneer Chain Saws recently introduced two "proved and improved" models of their 1961 product line with a full line of match-mated attachements. Featured in the new line are the all-new compact high-production model 410—for pulpwood cutting, falling, bucking and trimming; and the new professional model 610, a heavy-duty chain saw engineered and woods-tested to meet the most exacting demands of professional woodsmen.

Pioneer Chain Saws is part of the Outboard Marine Corporation Engines and Equipment Division. **Circle Item 9**



Automatic Hopper Feed

A new versatile, highly-productive automatic hopper feed has been developed by the Pistorius Machine Co., Inc.

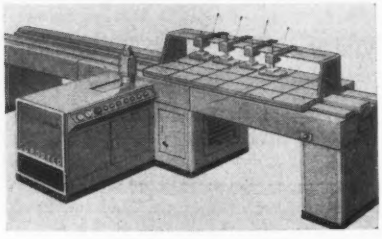
This unique unit maintains constant output, handles wide work range, feeds random lengths, and produces unmarred work, thus minimizing cutting Requiring only one operator, the Pistorius Hopper Feed greatly reduces labor costs while markedly increasing production.

Costly hand feeding is eliminated. Material is simply, quickly top-loaded into magazine. Adjustable pusher dogs on endless chain continually wipe out bottom pieces and advance them into machine feed. An electromagnetic clutch allows feeder to catch up and butt against preceding piece, and then conform to actual machine rate of feed. **Circle Item 10**

Steel Welded Wooden Pallet

Flow Products, Inc. announces the introduction of a steel welded wooden pallet known as the Gibraltar Pallet. The pallet is believed to be of the strongest construction ever manufactured regardless of material, and offers the user the lowest possible per-use cost. The Gibraltar Pallet is said to be at least 3 times stronger than pallets put together with conventional fasteners. The wooden parts are united with various forms of steel in a fashion so that the inherent strength of each will support, overlap and bridge any weakness of the other.

Circle Item 11



High Production Shaper

Current availability of a completely automatic, high speed hydraulic shaper has been announced here by the C. O. Porter Machinery Company. According to Dale Porter, company president, the Model 250 Shapemaster represents considerable advantages over previous production shaping equipment.

The Model 250 incorporates a self-contained power unit coupled with a redesigned cutting table which can accommodate stock of any width in lengths up to 100 inches. Improved smoothness through intricate cuts, with no appreciable reduction in feeding speeds, is claimed for the new Shapemaster machine. A cutter head speed of 8500 rpm, belted directly to a choice of motors from 10–20 hp. provides maximum cutting efficiency.

Circle Item 12

Automatic Grade Stamper

The Cunningham Little Robot Automatic Lumber Grade Printer is a simple but effective device designed to meet the problems that arose from the FHA and Veterans Administration's new rules which require the grade mark of an approved agency or species association on all framing and board lumber used in FHA and VA-insured houses.

Invented by a north Idaho Lumberman, W. O. Cunningham, Jr., owner and operator of the Deep Creek Planing Co. mill, the Little Robot is a small, compact piece of equipment that fits into either the trimming or grading chain. It comes ready-wired with a five-button control panel and needs only to be plugged into a convenient electrical outlet. Robots in operation now have a button for each of four grades, plus a cancel button. Regular Western Pine Association stamps are used.

The Little Robot is said to cost considerably less than any other piece of equipment for grade-stamping now on the market, and installation is inexpensive.

Circle Item 13

All-Purpose Wood Preserver

Oz Wood Preserver, a new all-purpose, water-repellent product, has been announced by Osmose Wood Preserving Company of America, Inc., pioneer manufacturer of wood preservatives. The product contains Butinox (R), made with a liquid organotin chemical produced by Metal & Thermit Corporation. According to soil block tests in Osmose Laboratories, the new product has been proved to be twice as toxic to fungi and termites than either copper naphthenate or pentachlorophenol. Oz meets or exceeds requirements of the National Woodwork Manufacturers Association.

Circle Item 14

Fire Fighting By Air Told in Booklet

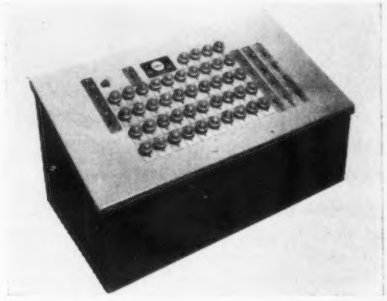
Through progressive ideas of energetic men who have worked with aircraft, Forest Service has saved millions of acres from fire, according to "Air Attack on Forest Fires," 32-page illustrated booklet issued by USDA. Forest Service believes use of airplanes & helicopters is most important advance in forest fire fighting over past half-century. "Air Attack on Forest Fires" is illustrated with either wash drawings or photographs—or both—on every page. Write: Forest Service, USDA, Wash.

Circle Item 15

Curtis Machine Brochure

A brochure by the Curtis Machine Division of Carborundum sets forth the specifications and advantages of its Curtis 150 series of abrasive belt machines for woodworking and metalworking industries. Handles work pieces 1/20 inch to 3 inches thick to 49 inches wide. Infeeds up to 100 linear feet per minute.

Circle Item 16



Relay Control System

A new simple system of relay control designed for any combination cylinder positioning systems, including line bars, edgers, etc., has been announced by Republic Electric & Development Co. of Seattle.

Easy to understand and easy to service, the Redco Edger and Line Bar Control eliminates complex circuitry. A typical system which formerly used 11 relays now uses only 4 simple plug-in relays with the Redco control. Reduction of the number of components also lowers installation costs, as all control can be located and prewired in the operator's console. No separate relay panel is required, and the only wiring is directly to the valves.

Circle Item 17

See Reader Service Form, page 12-A

What's New in *Technical Publications*

Single Copies of the Following Reports are Available Free Upon Request from the Director, U.S. Forest Products Laboratory, Madison 5, Wis.

Eight new or revised reports dealing with wood and its related subjects have been isssued by the U.S. Forest Products Laboratory here.

In **Report 2202,** "The Performance of Wood in Fire," are presented some research accomplishments in the field of pyrolysis and combustion of wood.

Various means of checking the retention and penetration of preservatives in treated poles are described in **Report 2206,** "Inspection of Preservative Treatment of Poles."

Experiments leading to the development of tempered hardboards from Ohia, a major species growing in the Hawaiian Islands, are presented in **Report 2205,** Hardboard from Ohia."

The expansion and contraction of free films of house paints with changes in temperature are described in **Report 2204,** "Thermal Expansion of Free Films of House Paint."

In **Report 2164,** "Drying Stresses and Stress Relief in Thin Sections of Wood," is explained a method to evaluate stresses and strains in casehardened veneer by measuring the bowing of slices cut parallel to the veneer surface.

Revised and brought up to date are three lists of publications that include **Report 238,** "Chemistry of Wood and Derived Products;" **Report 790,** Logging, Miling, and Utilization of Timber Products;" and **Report 508,** "Fungus Defects in Forest Products and Decay in Trees."

Lake States Station Releases Two Reports

Two reports have just been released by the U.S. Lake States Forest Experiment Station, University of Minnesota, St. Paul, Minn.

One report Station Paper No. 85, provides a new look at pulpwood procurement in the Lake States, showing the amount of pulpwood cut in 1959 by species and counties in Minnesota, Wisconsin and Michigan. In announcing the report, M. M. Dickerman, Director of the Station, emphasized that such detailed statistics reflect a changing pattern of timber supply and demand.

A field procedure for determining the growth potential of aspen lands is the subject of Station Paper No. 86. The report, written by Rudolph Strothmann of the Experiment Station staff, points out the problem foresters have in estimating the productivity of deforested land or land now growing true species which the landowner would like to replace. Since quaking aspen grows on a broad range of soil types, it has the potential for being a good indicator of productivity for other species.

Canadian FPL Studies Electrical Resistance, Marine Structures

Tests carried out at the Ottawa Laboratory, Forest Products Laboratories of Canada, have indicated that wood which has been soaked in fresh water at some point in its history offers a higher electrical resistance at any given moisture condition than similar wood which has never been soaked. This effect is exactly the reverse of that obtained by soaking in salt water. The significance of this finding is important when considering the use of wooden poles for power transmission lines because a high resistance is most desirable in these poles.

The increase in electrical resistance as a result of soaking in fresh water is variable with time, with the increase in resistance being very large soon after soaking and gradually decreasing. Results to date indicate that as a permanent effect, the electrical resistance of wood which has been soaked in fresh water will be about double that of similar wood which has not been soaked.

Protection of Marine Structures

A recently released publication, Bulletin 126, titled "Protection of Wooden Structures in British Columbia Waters" constitutes a handy reference for all those who are connected with the construction, maintenance or use of marine structures on Canada's west coast. This report is the result of a long term study carried out by the Wood Preservation Unit of the Vancouver Laboratory. It presents, in concise form, information on marine wood borers, and methods of protecting marine structures on the B.C. Coast.

Dimensional Stability of Plywood

The dimensional changes which occur in wood with changes in moisture content are largely overcome in plywood as a result of the cross-laminated construction of the material. A change in dimensions of 0.5 percent with a change in moisture content from a soaked to an oven-dry condition is a figure which has been commonly employed.

A recent series of tests carried out at the Forest Products Laboratories of Canada has indicated an average change in dimensions of approximately 0.35 percent with a change in moisture content from approximately 25 percent to an oven-dry condition. These tests were carried out on Douglas fir, aspen poplar, and white birch plywoods, with little difference in results being obtained with the three species. On the basis of these results the maximum dimensional changes which might be expected in a 4 feet x 8 feet piece of plywood, under normal interior use conditions, would be approximately 0.03 inches in the 4 feet dimension and 0.06 inches in the 8 feet dimension.

Recent FPLC Publications

The following new publications are available on request from either the Ottawa or Vancouver Laboratory, Forest Products Laboratories of Canada, Forestry Branch, Department of Northern Affairs and National Resources.

"Pre-logging with a Portable Steel Spar," J. A. McIntosh and D. C. Gunn; "Lumber Degrade Caused by Ambrosia Beetles," C. F. McBride and J. M. Kinghorn; "Developing an Experimental Two-Piece Circular Saw Blade," J. S. Johnston; Mimeo. 0-183—"Grade Marking of Canadian Lumber for Export to the U. S. A.", J. H. Jenkins; "Prediction of Plywood Bond Durability," P. L. Northcott, and H. G. M. Colbeck; "Kiln-Drying of Unbundled Shingles at High Temperature," M. Salamon.

Oregon Conducts Study On Particleboard

Increase in demand for particle board may result from improvements now under study, according to R. A. Currier, in charge of research on manufactured products at the Oregon Forest Research Center, Corvallis. Currier is studying pretreatment of wood particles to improve dimensional stability of particle board.

Among pretreatments being tested are high temperatures applied to wood particles before and after particles are formed in a mat for processing. Special binders, impregnating chemicals, vapors, and oils also will be tested as methods of preventing shrinking and swelling. Controlling acidity of wood particles may prove beneficial, stated Currier.

Lumber Grading Course At Michigan State U

The fourth annual 5–day course in hardwood lumber grading will be held at Michigan State University, East Lansing, April 24–28, 1961.

The course is designed to benefit those engaged in the production, selling, buying, or use of hardwood lumber and to povide them with a basic knowledge and understanding of grading rules.

Registration fee is $35. For additional information write: Hardwood Lumber Grading Course, Continuing Education Service, Michigan State University, East Lansing, Mich.

Pressure Treated Posts Standard Released

A new Commercial Standard, designated CS235–61, for "Pressure Treated Wood Fence Posts (With Oil-type Preservatives)," has recently been released by the U.S. Department of Commerce. Standard sizes of round, half-round and square-sawn posts are given as well as wood species, preservatives, manufacturing processes and grading rules. (Another standard covering posts pressure treated with salt type preservatives, which will be based on the same tests, is under consideration). The new standard has been endorsed by producers who, according to the U.S. Forest Service, treated over 17 million fence posts in 1959, or better than 65 percent of the total 1959 production of all pressure treated posts.

 See Reader Service Form, page 12-A

CROSS SECTION

. . . Voice of Membership

Letter From The Editor

Mr. T. Walter Noble
Vice President and Technical Director
Decar Plastics Corporation
Middleton, Wis.

Dear Walt: Thanks for your kind words re our February news story on Decar. We are always pleased to be of service to members of the Society. With this in mind, I'd like to call your attention to *CROSS SECTION* which we started in the October issue with a note that read. . .

> "It is more than just a letters-to-the-editor column. It is a place where you, our readers, may discuss Society affairs, present problems, submit solutions, remark on past programs and future plans, as well as comment on *Journal* articles and editorials. We welcome your contributions."

We still welcome such contributions — but even more — we want *CROSS SECTION* to be of service to *you*. If you have a research problem and would like comments or suggestions from your colleagues, let us know. If you've solved a problem, developed a time-saving technique, improved a research tool — share the idea with your colleagues through CROSS SECTION.

If you have a production problem — if you are looking for supplies, new sources of raw materials, new equipment, or that special, hard-to-find product — let *CROSS SECTION* find your answer.

We welcome the opportunity to be of additional service to you, and all FPRS members, through *CROSS SECTION*.

JOHN K. MCDONALD, EDITOR
Forest Products Journal

New Plant Planned

Gentlemen: Our Managing-Director, President Ir. M. Elion is an associate member of your Research Society. Our company regularly receives the *Journal*. We are general contractors with our own woodworking plant, in which we manufacture joinery and all wood products for the building industry; laminated and glued long-span beams, rafters, sliding windows and doors, "concertina" and "bellows" doors; and kitchens and wardrobes.

We plan a new modern woodworking plant and should be very much interested in receiving the latest documents about machinery, kiln drying, mechanical wood transport (inside and outside the factory buildings), assembling and burning of wood-waste, gluing (including high frequency gluing), and large-space heating.

Could you give us the names and addresses of well-known firms which specialize in any of those subjetcs and, if possible, the name of some consulting engineers, who could give us impartial advice on preparing and selecting offers from the States.

BOUWNIJVERHEID
Oegstgeest, The Netherlands

Continuing Membership

Sirs: I am no longer in student status but would like to know if you have a membership program for service personnel. Inasmuch as I am in the service I cannot participate actively in the Society although I am still interested and would like to maintain membership.

ENSIGN JOHN O. RICHTER, JR.
USNR
USS Courtney (DE-1021)
FPO, New York, N. Y.

The Executive Board has formed a committee to study the possibilities of special membership fees for both retired and military personnel. Any suggestions received from members (note following letter) will be forwarded to this committee.—*Editor*

Executive Secretary: You ask for our thoughts on the subject of reduced dues for those who have retired. I am very much in favor of having something like this worked out. We give students reduced rates in order to keep them interested in the Society until they are out of school and can become full members . . . it is equally important that retired people be kept active in Society affairs. In this case, we seek their comments, help and promotional interest whenever and wherever they can give them. Certainly a move to keep them enrolled would be in order as an aid to carrying out such desires.

If we do right by these retired people, I can conceive that they will be willing to serve on arrangements or other committees and possibly even present papers; at any rate, I think they can be of invaluable service as long as their interest can be kept at a high pitch.

IRA HATFIELD, Director of Research
Wood Treating Chemicals Company
St. Louis, Mo.

Requests From Younger Set

Editor: I am a member of Girl Scout Troop No. 68. Our Scout Leader gave us each an assignment. . . . to write you and ask for literature and samples of the Forest Products you have handy. Anything you send me will be displayed at my school.

PAULA LEE HEINRICHS
2860 Queston Drive
Indianapolis 22, Ind.

Gentlemen: I am in the eighth grade. We are doing a report on lumber and its by-products. I wonder if you could send me some information on this subject. Pictures and graphs would be very helpful.

ERIKA KOSTRON
35 Columbia Avenue
Hopewell, N. J.

More Requests

Gentlemen: Please send information concerning water sprays for protection of hardwood logs, as described in your June, 1960, issue, p. 277. We are interested primarily in procedure, nozzle placement, and water pressure, and plan to spray beech, birch, basswood, hard and soft maple on top and both ends. The logs will be added to spray piles intermittently between May 1st and July 1st, to be sawed in August.

FRED R. LITTLE
Little Lumber Company
Delancey, N. Y.

FPRS SECTION MEMBERSHIP GOALS

Wanted: 300 New Members by June 1, 1961

Section	New V. & A. Members Section Goal	Percent of Goal Attained	Membership Chairman
Midwest	30	56	R. C. Newstedt
Ohio Valley	10	60	H. E. Cook
Great Lakes	20	40	N. C. Franz
Upper Mississippi Valley	10	10	L. A. Ropella
Mid-South	25	92	H. L. Russell
Northeast	50	44	R. F. West
Eastern Canadian	20	85	Alfred Glennie
Carolinas-Chesapeake	25	80	Sam Freeman
Southeastern	10	100	P. J. Bois
Pacific Northwest	50	36	Tom McKenna
Inland Empire	10	60	R. L. McNett
Northern California	20	65	Victor Roth
Rocky Mountain	10	30	R. S. Bader
Pacific Southwest	10	110	W. E. Ripley, Jr.

As of March, an overall total of 58% of the membership goal has been attained. P. J. Bois, Southeastern, has achieved 100 percent; W. E. Ripley, Jr., Pacific Southwest, is the first to exceed his goal with 110 percent attainment. How many more will top their goals before June?

Help your membership chairman meet his quota!

See Reader Service Form, page 12-A

FPRS FOREST PRODUCTS JOURNAL VOL. XI, NO. 3 MARCH, 1961

RESISTANCE OF CASEIN GLUE JOINTS

To Shear Fatigue Stressing[1]

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SOUND STRUCTURAL DESIGN is based on the knowledge of elastic and mechanical properties of the material and of the variation of these properties.

New construction methods and the use of new materials, or the unconventional combination of known materials, may require an extension of our knowledge of basic material properties. This knowledge of basic material properties can only be acquired in well-controlled laboratory tests.

The increasing use of glue-laminated members in recent years is an indication that glue has been accepted as a structural fastener. The limitation of gluing technique to side-grain gluing due to the anisotropy of the wood is the reason that glue lines are subjected to shear stresses exclusively in the majority of applications in structural members. The static strength of a glue line in wood is somewhat difficult to determine for two reasons:

1. It is difficult to subject the glue line to pure shear stresses.
2. In many cases, the glue line can not be stressed to failure because of the low shear strength of the wood.

It can be suspected that the apparent shear strength of the glue line as obtained from standard static tests tends to be on the low side, thus providing a certain safety factor, in addition to other safety factors usually recommended to compensate for various defects. Results from standard tests, however, are not always valid representations of the material's true properties under service conditions.

Often a structure is subjected to loads of varying magnitude. This magnitude may, under different circumstances, vary from a maximum of 100 percent of static strength of the material to a minimum of zero percent. Sometimes this difference may even become larger when the member is exposed to reversed stressing. In service, however, such a large fluctuation in stress is not likely to occur.

[1] A 1960 Wood Award entry. Revised version received for publication Jan. 9, 1961.

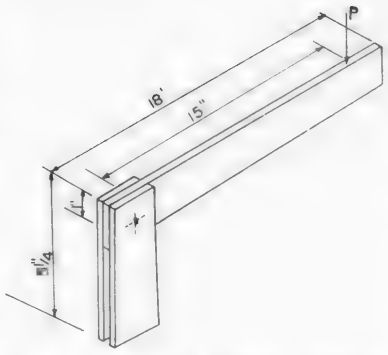

Fig. 1.—The type of specimen employed in this investigation. Note that the point of load application is 15 inches from the center of joint.

In the past century, the behavior of materials under repeated loads has been of considerable interest, and its understanding has become extremely important. This type of loading is referred to as fatigue loading, which causes progressive damage and eventually complete failure in most engineering materials. In other words, fatigue is the phenomenon of failure under repeated stresses.

While voluminous literature is available on the fatigue properties of crystalline materials such as steel, corresponding information on wood and adhesive bonds is indeed limited. The fact that the static shear strength of the wood in many cases is lower than the shear strength of the glue line does not necessarily indicate that this will be the case if the assembly is subjected to fatigue stressing. Although it has been found that the fatigue strength of the glue bond, in some cases, is almost the same as that of the solid wood (3)[2], not enough assurances of such type are available for various types of glue-wood combinations. The objective of this paper was to investigate the fatigue resistance of casein joints while using a new type of test specimen.

[2] Numbers in parentheses refer to the Literature Cited at the end of this paper.

Test Specimen

The following considerations were important factors that influenced the design of a suitable shear specimen and the selection of adhesive type and wood species:

1. It was desirable to develop pure shear stresses in the glue line.
2. Since the ultimate stresses (at failure) are the important characteristics in fatigue testing, the specimen had to be so designed that shear failure would occur in the glue line before the applied stresses would reach a destructive level in the wood.
3. Due to limitations of the fatigue machine used, the specimen had to be so designed that the maximum shear stresses would be equivalent to a total load of less than 50 pounds.

When the above factors were considered, it was decided to subject the specimen to torsion rather than to simple shear, as is common practice in most standard shear specimens. Torsional shear stresses can be developed either in a cylindrical plane parallel to the axis of rotation or in a flat plane

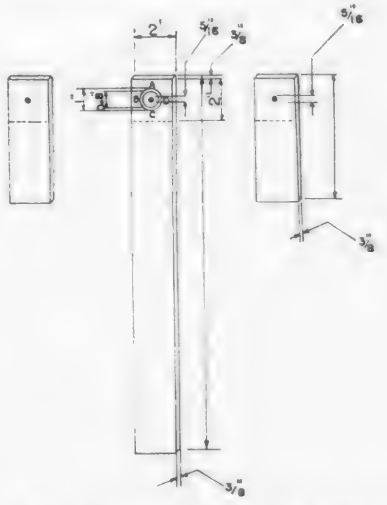

Fig. 2.—Detailed dimensions of the three members of each specimen. Note the circular glue line on the joint.

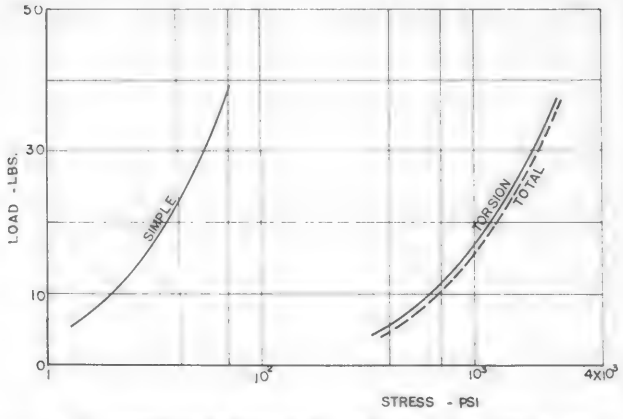

Fig. 3.—Comparative magnitudes of torsional and simple shear components of the stress pattern employed.

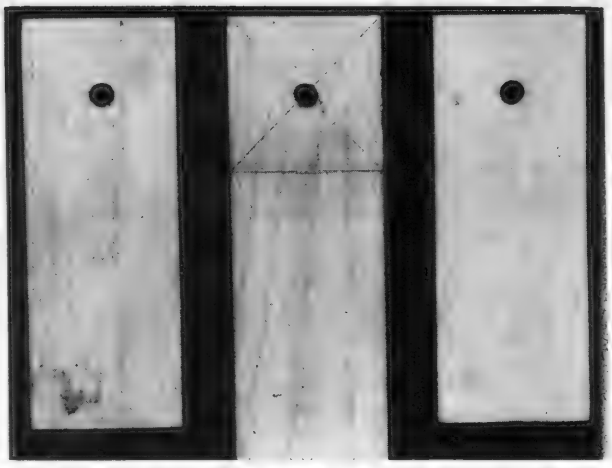

Fig. 4.—Three parts of members of the test specimen. The joint area, except the circular ring, was covered with cellophane tape.

normal to the axis of rotation. Since glue spread and laminating pressure can be more easily controlled on a flat plane, the latter design was chosen.

When a flat plane oriented perpendicularly to the axis of rotation is twisted, this plane will be distorted unless it is a complete circle with its center at the axis of rotation (1, 2). This design, however, has the disadvantage that the torsional shear stresses are a function of the distance from the center of rotation. To reduce this variation of the shear stresses as well as to keep the total glue line area small enough so that a total load of less than 50 pounds operating on a torque arm of practical length would cause the glue line to fail, the glue area was limited to a narrow concentric ring around the axis of rotation. The specimen and its dimensions are shown in Figs. 1 and 2.

In addition to torsional shear, the load P operating on a 15-inch torque arm develops simple shear stresses of a magnitude P/A, where A is the total glue-line area. The magnitude of this component of the total shear stress is appreciably small compared with the torsional component, which is calculated below.

The total shear stress on the glue line is the sum of the torsional and simple shear components as expressed in the notation below:

$$\tau_{tot} = \tau_s + \tau_t$$

The simple shear component is:

$$\tau_s = \frac{P}{A}$$

Hooke's law indicates that $\tau_t = G\epsilon$ where G is the shear modulus and ϵ is the shear strain.

Since shear strain is given by

$$\epsilon = \frac{r.\theta}{L}$$

where: r = radius of circle; θ = angle of twist; and L = thickness of the glue line.

The torsional stress is: $\tau_t = \frac{G\theta}{L} r$

The torque created in this case is

$$T = \int r\tau_t dA$$

By substituting for τ_t we get:

$$T = \frac{G\theta}{L}\int r^2 dA$$

which after integration becomes

$$T = \frac{G\theta\pi d^4}{32L}$$

where d represents the diameter of the circular area.

For the specimen used in this study, the glue area was confined to an area located between two concentric circles with diameters d_1 and d_2, where $d_1 > d_2$. For this case:

$$\int r^2 dA = \frac{\pi}{32}(d_1^4 - d_2^4)$$

$$\text{and } T = \frac{G\theta\pi}{32L}(d_1^4 - d_2^4)$$

The maximum torsional stress is given by:

$$\tau_{t(max)} = \frac{G\theta}{L} r_{max} = \frac{G\theta}{2L} d_1$$

$$\text{or } \tau_{t(max)} = \frac{16Td_1}{\pi(d_1^4 - d_2^4)}$$

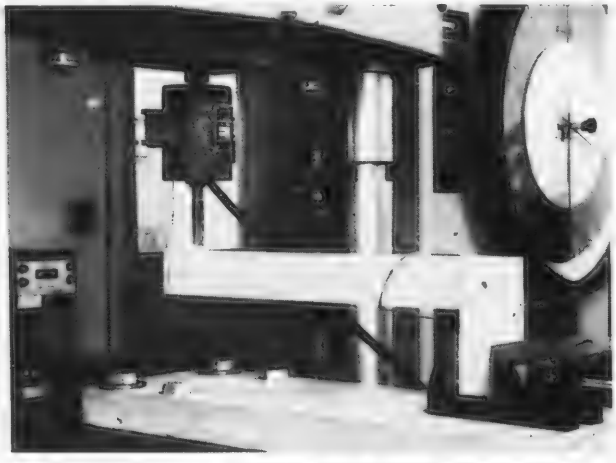

Fig. 5.—The specimen mounted on the static testing machine. Note the overhanging load cell.

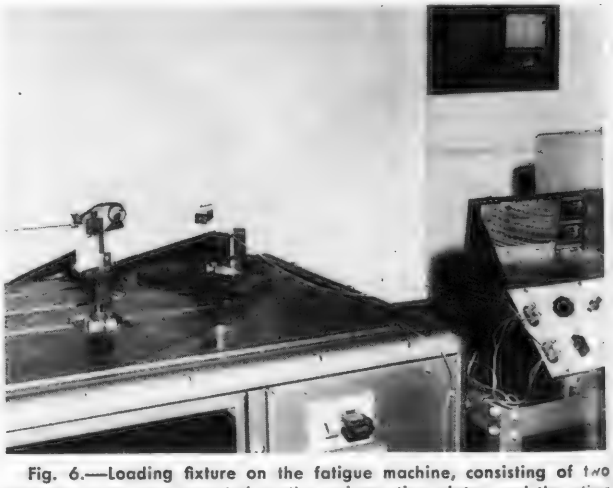

Fig. 6.—Loading fixture on the fatigue machine, consisting of two separate parts; one mounted on the reciprocating platen and the other attached to the heavy stationary platen.

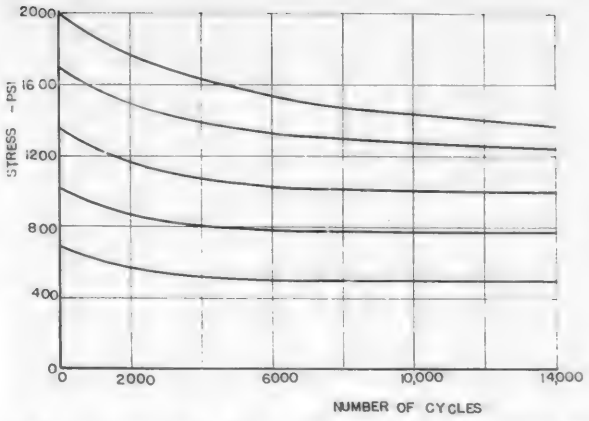

Fig. 7.—Stress drops due to occurrence of wood crushing and ossibly creep phenomenon in the joint for five predetermined stress vels.

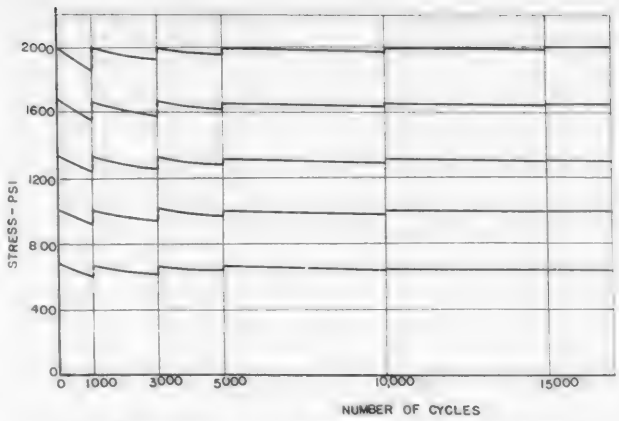

Fig. 8.—Adjustment curves showing compensation of wood crushing and creep effect.

comparison of the two stress components for various loads is shown in ig. 3. The maximum magnitude of his stress pattern occurs at the point where the two stress components simple and torsional) have the same algebraic sign. Point C in Fig. 2 corresponds to such a point. On the opposite side of the circular glue line (point A), where the torsional stresses are directed upwards, the total shear stress would be equal to the torsional shear stress reduced by the simple shear stress. In this case, the two stress components have different algebraic signs.

In the selection of wood species and adhesive, it was necessary, for obvious reasons, to find a combination that would result in glue failure, at least in the static testing.

Hard maple and casein glue is such a combination in which the wood has a relatively high shear strength (6) and the glue is an important representative of commercially used structural binders.

Preparation of Test Specimens

Defect-free hard maple stock was used. After the members of the specimens were cut and planed, the circular glue line was established. To accomplish this, those portions of the horizontal member (longer member) of the specimen that would intersect the vertical members were covered with a 2-inch-wide cellophane tape. The thickness of the tape was on the order of magnitude of a normal glue line (0.002 inch). After the tape was applied, the ring-shaped glue line 1/10 inch wide was cut out (see Fig. 4). To eliminate the possible effect of tape residue on the outcome of testing, the tape was kept loose in the central portion where the glue line was to be cut out. After the ring-shaped glue line was cut out, the tape was gently pressed down to cover the entire area of the joint with the exception of the glue line. Preliminary testing revealed that there was no bond formed between the members of the specimen on that portion of the joint covered with the cellophane tape. At this stage, the specimens were conditioned at 70° F. and 60 percent relative humidity for 10 days. Moisture content values determined after this period and immediately prior to the gluing operation were 6.0 to 7.8 percent for all specimens.

The gluing operation was performed in a jig made for this purpose. Predetermined pressure of 200 pounds per square inch was applied to the joint by tightening a bolt, which transferred the pressure via two large washers to the joint. This arrangement was believed to result in a uniform pressure distribution. The pressure was applied by means of a torque wrench.

After the specimens were assembled, they were stored in the conditioning room for five additional days. Moisture content determinations after this period of five days showed practically no change. That is, the moisture content still ranged between 6.0 and 7.8 percent.

Testing Procedures

The static shear strength of the glue line was determined on 25 out of a total of 75 specimens. The remaining 50 specimens were subjected to fatigue stressing at 5 different stress levels with 10 specimens at each level.

The static testing was performed on a Baldwin Emery Universal testing machine equipped with a load cell that measured the applied load to the nearest 1/10 pound. The load was applied at a uniform rate of deflection of 0.018 inch per minute. The mount-

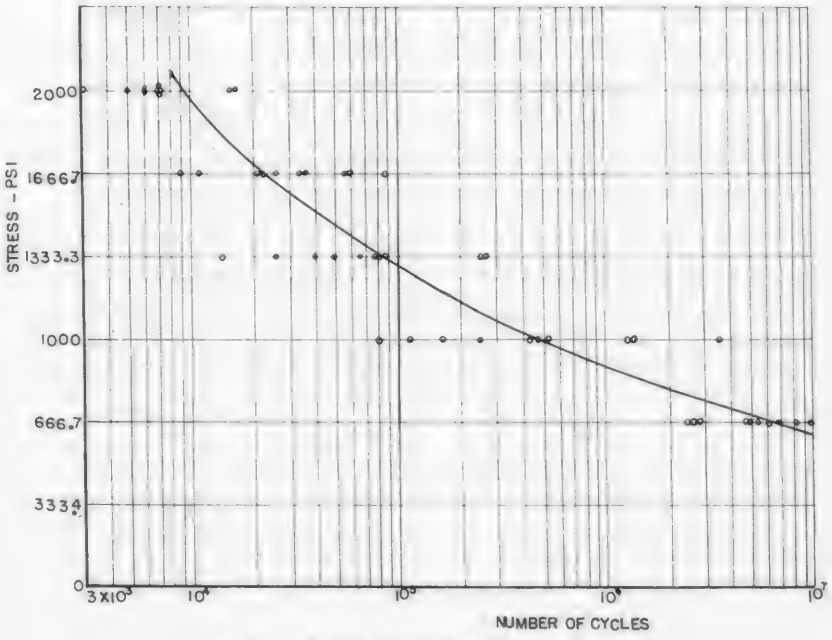

Fig. 9.—S–N curve developed for casein glue line.

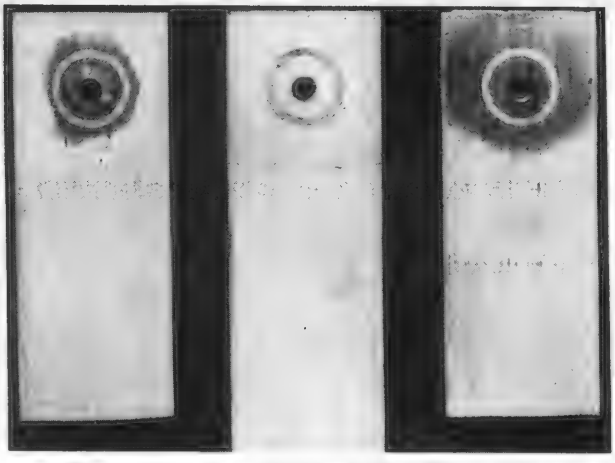

Fig. 10.—A specimen that failed during fatigue testing. Pure glue line failure is evident.

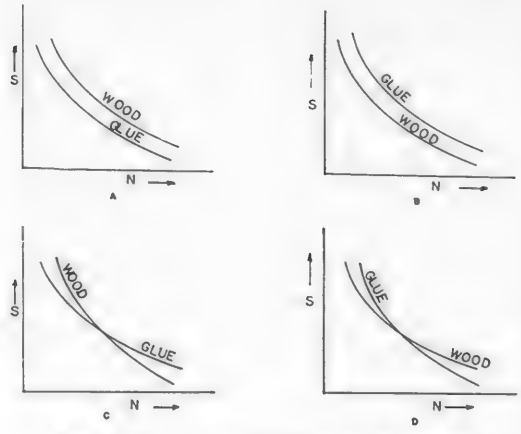

Fig. 11.—Hypothetical S–N curves for glue-wood

ing of the specimen is illustrated in Fig. 5.

The fatigue tests were carried out on a Sonntag Fatigue Machine. This machine subjects the specimen to an oscillating force transmitted by a reciprocating platen that oscillates at a rate of 1800 cycles per minute at constant amplitude. The mounting of the specimen is shown in Fig. 6. The steel sleeve over the end of the horizontal member is bolted to the oscillating load applicator, and the vertical members are held in another part of the fixture, which is fastened to the stationary platen of the machine. The shear stresses developed at the 5 different load levels covered a range from 83 to 23 percent of the average ultimate shear stress found in static testing. The minimum stress in each cycle was zero. The actual load applied to the specimens could be checked by means of an oscilloscope, which measured the strain on the specimen. As shown in Fig. 7, a considerable stress reduction occurred during the first part of each test. This reduction was caused by a certain amount of wood crushing at the point of loading and possibly by creep in the glue line. Several adjustments were necessary during the first 15,000 cycles after which the stresses remained at the constant preassigned magnitude (Fig. 8).

There was very little wood failure in either static or fatigue tests. As Table 1 indicates, the wood failure in static testing was less than 10 percent of the total glued area in most cases. This infers that, in this particular case, the glue line itself was the weakest link of the joint. In the fatigue tests, the result in this respect was nearly the same.

Discussion and Results

Since the grain directions of two adjacent members forming the joint were at an angle of 90 degrees, changes in moisture content of the specimens could have had considerable influence on the outcome of the experiment. But, as was noted before, there was practically no change in moisture content between the time of gluing and static testing. In the fatigue testing, there was no significant decrease or increase in moisture content at 4 of the 5 preassigned stress levels. At the fifth stress level, however, a maximum drop in moisture content of about 1.8 percent was observed. A higher stress relaxation would be expected to occur under these circumstances. But, as Fig. 7 illustrates, the stress relaxation at the fifth stress level was not unusually high as compared with the four other stress levels.

Relaxation, that is, the reduction of stress during the test, has been illustrated in Fig. 7. These stress drops could be due to either of two factors, or both: 1) occurrence of creep in the glue joint; 2) local wood-fiber crushing in the steel sleeve or other parts of the fixture on the fatigue machine (see Fig. 6). To reduce the effect of the latter, pieces of 1/8-inch-thick rubber were placed under the two semicylindrical parts of the steel sleeve that transferred the load to the specimen, as well as under the other parts of the fixture where pressure was being applied to the specimen.

The stress drop at all five stress levels was significant. Fig. 8 illustrates adjustments made in order to keep the stress at constant level. In the fatigue machine, these adjustments were made at intervals indicated in Fig. 8.

Results of fatigue tests are customarily represented in the form of a S–N curve which graphically shows the relation between the stress, *S*, and the number of load cycles, *N*, after which failure occurs.

For some materials, such as steel, the S–N curve levels off at a certain stress level. This leveling off indicates that no fatigue failure will occur at this particular stress level or at any lower level. This limit, termed "endurance limit" was not reached in this study. In such a situation, the stress level at which the specimens resist 10 million cycles is taken to be the endurance limit for most practical purposes.

The S–N curve for casein joints in hard maple shown in Fig. 9 was developed according to standard procedure for analyzing fatigue data (5). The fatigue strength at 10 million cycles is about 600 pounds per square inch. This is approximately 25 percent of the average ultimate static strength of the joint as recorded in Table 1.

If it were possible to plot the S–N curves for the glue and the wood species separately, four general cases depicted in Fig. 11 are apt to occur. Fig. 11A, for instance, illustrates the case where the fatigue strength of the wood species is higher than that of the adhesive used for all applied stresses. In

Table 1.—DATA RECORDED FOR CASEIN JOINTS IN STATIC TESTING

Ultimate load lbs.	Calculated stress[1] psi	Wood failure[2] Side 1 percent	Wood failure[2] Side 2 percent
36.3	2420	0	0
38.7	2580	0	0
39.0	2600	10	10
33.0	2200	0	10
31.2	2080	10	10
36.0	2400	10	10
39.0	2600	0	10
36.5	2430	10	10
40.0	2670	10	10
30.0	2000	0	10
33.8	2250	10	10
35.5	2370	10	0
34.5	2300	10	10
34.5	2300	0	10
38.0	2530	10	10
37.3	2490	10	10
36.3	2420	10	0
34.8	2320	0	10
34.3	2290	0	0
35.2	2370	10	10
38.0	2530	10	10
36.5	2430	10	0
38.2	2550	0	10
36.8	2450	0	10
36.0	2400	0	10

[1]Average calculated stress 2398.37 psi. Standard deviation of ave. cal. stress 160.8 psi.
[2]The figure 10 in third and fourth columns of this table indicates that the wood failure is less than or equal to 10 percent of the total glued area.

such a case, the fatigue failure takes place in the glue, thus leaving very little or no wood failure on the glue line. Figs. 11B through 11D illustrate other possibilities.

The study described in this paper seems to correspond to the case of Fig. 11A, where for all stress levels, the fatigue damaged the glue but caused no or very little wood failure. In such a situation the S–N curve shown in Fig. 9 is assumed to represent only the casein glue, with no interference by the wood species. On the other hand, in this case under the experiment's circumstances, the hard maple fibers in the glued area exhibited better fatigue resistance than did the glue.

Conclusions

The fatigue strength of casein glue lines determined by the methods described above indicates that, at 10,000,000 cycles, the practical end point in fatigue testing, this strength is only 25 percent of the average static strength of the joint. In this study, however, in each cycle, the stress at all stress levels oscillated between zero and the maximum of the preassigned stress. In other words, the minimum repeated stress was zero percent of the maximum stress per cycle. This results in a shorter fatigue life than if the stress oscillated from 10 percent to the same maximum stress (4).

It can not be concluded from static shear tests alone that the fatigue characteristics of glue lines will show the ideal behavior hypothetically depicted in Fig. 11B, where the fatigue strength of the glue is higher than that of the wood used. If such a case is encountered, the glue bond itself is no longer of major concern since failure is very likely to occur in wood and not in the glue line.

In this study, results correspond to Fig. 11A, where the glue bond failed first in fatigue stressing because of indication of no significant wood failure throughout the test.

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Magnefite Pulping of Douglas-Fir [1, 2]

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The sulfite pulping process is on a new competitive level. If acceptable pulp can be made from Douglas-fir, wood costs can be lowered by use of chips from residues of sawmills and veneer mills. Data here reported indicate strength values of Douglas-fir pulp made by the Magnefite process were excellent. Aspects for recovery and pollution abatement also appear favorable.

IN THE PAST TWO DECADES, developments of the sulfite process have carried it from the brink of obsolescence to a new level of competitive vigor. As late as 15 years ago, sulfite operations appeared doomed to early extinction because of the problems of pollution abatement, limited pulp strength, and limitations as to suitable wood supply.

A number of important innovations have contributed to the advances in sulfite technology. The neutral sulfite process developed by the U. S. Forest Products Laboratory is particularly well-suited to production of high-yield pulps from hardwood. Magnesium-base pulping pioneered by Weyerhaeuser Timber Company has offered a feasible recovery system which provides pollution abatement and process economy. This development resulted in installation of additional sulfite capacity that probably would not otherwise have been possible.

Most recent developments have been exploration of the intermediate pH range of sulfite liquors; that is, operation in the range pH 3.0–5.0 (1, 2)[3]. Essentially, this represents a compromise between neutral sulfite and acid processes in an attempt to obtain high strength and wood-supply flexibility of neutral sulfite, and low temperatures and chemical requirement of acid sulfite. The mid-range of liquor pH is obtained with solutions of essentially the bisulfite salt of the given base sodium, ammonium or magnesium. Calcium bisulfite is not suitable for this type of liquor, because of its limited solubility. These solutions contain little, if any, true free SO_2, so excess pressure caused by SO_2 vapor is much less than in acid sulfite. The use of magnesium bisulfite solution in the Magnefite process provides a particular advantage in recovery of chemicals. Spent liquors from magnesium-base liquor, when burned under proper conditions, yield largely sulfur dioxide and magnesium oxide, both of which can be used directly in preparation of new liquor (3). With sodium base, the products of combustion are complex, and further processing is required in conversion to sodium bisulfite solution. Promising methods of recovery for sodium-base sulfite have been developed to the point of large-scale trial; magnesium base is, however, the only sulfite-recovery system having commercial-size operations of sufficiently long standing to clearly establish economic data (4, 5).

In the Pacific Northwest, a limitation of the conventional acid-sulfite process is its dependence on West Coast hemlock and true firs as wood supply. Currently, savings in wood cost in excess of $10 a pulp ton could be made by using Douglas-fir chips available from residues of sawmills

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[1] Presented at the Wood Industries Conference in Portland, Oregon, September 10–12, 1959. Approved for publication February 12, 1960.

[2] The author gratefully acknowledges advice and suggestions of D. W. Glennie and the experimental work of C. A. Perkins.

[3] Numbers in parentheses refer to Literature Cited at the end of this article.

Table 1.—WOOD DATA ON DISK SECTIONS

Height in tree Feet	Sapwood content Percent*	Sapwood Specific gravity	Sapwood Springwood volume Percent	Heartwood Specific gravity	Heartwood Springwood volume Percent	Springwood volume, over-all Percent
4	65.6	0.53	52.3	0.45	61.3	55.5
16	63.0	0.51	51.1	0.43	60.9	54.6
60	74.4	0.43	---	0.38	---	67.5

*By weight.

and veneer mills. Calcium-base acid-sulfite pulping of Douglas-fir is considered impractical because of resistance of its heartwood to penetration of cooking liquor, and catalytic breakdown of the cooking acid that leads to precipitation during the cook. Soluble-base acid-sulfite processing is more practical in operation, but pulps obtained have deficiencies in brightness, burst, tensile, fold, and forming qualities when compared to pulps of West Coast hemlock, or white fir. Any improvements in pulp properties that would allow use of Douglas-fir pulp in mixed sulfite furnishes would contribute to process economy by reducing wood cost through increased utilization of Douglas-fir mill residues.

In previous trials directed to production of improved sulfite pulp from Douglas-fir, liquors prepared from sodium sulfite and bisulfite were used in a semichemical process (6). After 3-stage semi-bleaching, these pulps had properties similar to those of conventional news sulfite prepared from hemlock. Costs for wood and chemicals for the two processes were nearly equal, but the short cooking cycle for semichemical pulp probably would not offset additional costs for fiberizing and bleaching equipment. Although the biochemical oxygen demand of spent liquor from the semichemical process would be lower, when the bleaching effluent was considered, the semichemical process could offer little, if any, advantage for pollution abatement without recovery. Although overall costs were similar for 3 different wood samples, optimum distribution of chemical between cooking and bleaching was different. In any commercial operation, such variation of results with changes of wood supply could cause grave difficulties both in process economy and in quality control.

Magnefite Pulping of Douglas Fir

Variability is one of the outstanding characteristics of Douglas-fir wood. A brief study of variation of heartwood content in chips from residues of sawmills and veneer mills in Oregon (7) was accompanied by trials of pulping heartwood and sapwood to determine some of the effects of heartwood content of chips on their potentialities as a pulping raw material. Since the work of Tomlinson et al (8) with Magnefite pulping of Eastern hemlock, spruce, cedar, pine, tamarack, and hardwoods indicated great versatility as to raw material as well as recovery processes for pollution abatement. Magnefite trials were made to compare Douglas-fir heartwood and sapwood.

Raw Material: To eliminate possible variations arising from differences in growth area, physical qualities of chips and chance contamination, laboratory-prepared chips from a single young-growth Douglas-fir tree were selected for the comparison cooks. The sample tree, a 45-year old, co-dominant, was collected from a thinning area of Black Rock State Forest, Site III. Eighteen 4-foot bolts were collected, the uppermost bolt having a 7-inch top diameter. Test data on disk sections of these bolts are shown in Table 1.

Note that the heartwood contained a greater amount of springwood than did the sapwood.

A property of Douglas-fir of potentially significant effect in pulping is its variation in permeability. Recently, a survey of the geographical differences in permeability of Douglas-fir specimens collected in Oregon was made by Graham and Miller (9). In this survey, data on permeability were taken on heartwood specimens collected throughout the State. Specimens from west of the Cascade Mountains were most permeable and those from east of the Cascades, least permeable. Similar data for specimens from our pulping raw material showed lower permeability than would be expected from its origin. Sapwood specimens from the tree studied were slightly less permeable than were heartwood specimens from coastal Oregon. Heartwood specimens were lower in permeability than were sapwood specimens, as would be expected. Both heartwood and sapwood specimens were somewhat less permeable near the top of the tree than near the butt.

Further work is in progress to evaluate the role of permeability in cooking and to explore methods for improving both penetration and stability of liquor.

Cooking Procedure: All cooks reported were made in a 6-liter bomb-type experimental digester with circulation and external heating. Maximum cooking temperature was 330° F., which was reached after 1½ hours. Liquor temperature was increased to 220° F. in 10 to 15 minutes After an hour of cooking, temperature was raised to 330° F. during a half-hour period and held at 330° F. thereafter. Magnesium bisulfite liquor of pH 4.5 preheated to 160° F. was used for all cooks. Liquor volume was adjusted with water to obtain a liquor-to-wood ratio of 5:1, including water in the wood chips. No overhead relief was taken during the cook. Time at temperature was determined by liquor decomposition. In all instances, cooking was terminated when combined sulfur dioxide and pH fell sharply. At this point, a precipitate appeared in the liquor.

On several cooks, chips were pretreated with water or a 1 percent solution of borax or sodium hydroxide. Ratio of treating solution to chips in the digester was 4.5:1. Circulation and heating were started, and the temperature was brought to 250° F. in 10 minutes and held there for 50 minutes. At the end of the treatment, treating solution was drained from the digester, cooking liquor was charged, and the cook was started.

Although satisfactory pulping was obtained under these conditions, limited study did not develop evidence that conditions were near optimum for pulping Douglas-fir. Since temperature,

Table 2.—DATA FOR REPRESENTATIVE COOKS

Wood	Combined SO_2 applied Percent[1]	Time at max. temp. Minutes	Total yield Percent	Screenings Percent	Screened yield Percent	K No.	Photovolt brightness	Strength at 500 cc C.S.F. Mullen Percent	Strength at 500 cc C.S.F. Tear Percent
Sapwood	14	168	50.4	1.6	49.6	11.5	43.0	96	170
Heartwood	14	140	62.8	19.7	50.4	23.4 (24.8)[3]	19.0	102	117
50–50	14	157	52.3	5.6	49.4	14.4	33.2	94	145
Heartwood	20	185	51.8	11.0	46.1	13.2	28.0	106	135
Heartwood[2]	14	165	50.3	4.9	47.8	16.0	25.0	110	130
Tappi Reference Standard A	-	-	-	---	-	---	---	44	143

[1]Based on oven-dried weight of chips.
[2]Pretreatment conditions: 5:1 water-to-wood ratio, 10 minutes to 250 F, 50 minutes to 250 F. Solution drained from chips.
[3]Permanganate number values in parentheses obtained using 40 ml of 0.1 N $KMnO_4$ and 4 N H_2SO_4; other values were obtained using 25 ml of each solution.

liquor pH, and cooking pressure are interrelated, a lengthy study would be required to optimize each factor.

Tests made on samples of liquor removed from the digester during the cook showed that pH fell more rapidly when cooking heartwood than when cooking sapwood. The final drop in pH, which coincided with formation of a precipitate in the liquor, also occurred sooner with heartwood than with sapwood (Figure 1). Pretreatment with hot water apparently reduced the amount of acid-producing constituents in the wood chips, causing the course of liquor pH with heartwood to progress somewhat like sapwood. The effect of pretreatment with borax and caustic solutions was difficult to interpret, because of effect of alkalinity of the residual pretreating solution.

The course of the liquor pH would have been substantially different if excess pressure had been relieved during the cook. Ingruber has shown that pH can be controlled by adjusting the pressure in acid sulfite cooking (10). This has been confirmed in trials where relief of excess pressure tended to defer drop in pH and slow the cooking action.

Cooking Results: From data on cooking trials and results of pretreatment experiments shown in Table 2, one can see that greater amounts of applied chemical to reach a given permanganate number were required with heartwood than with sapwood. Whether permanganate number accurately predicts bleach demand is somewhat questionable. Flavanones have been reported to influence permanganate numbers excessively (11). The higher flavanone content of heartwood pulp would tend to make comparison of permanganate numbers misleading (12). From Table 1, one can see that to obtain a given permanganate number, higher chemical was required for heartwood than for sapwood. The mixture appeared to be intermediate in chemical required; close to that predicted from separate trials of sapwood and heartwood.

Results of the pretreatment pulping trial shown in Table 2 indicate that hot-water pretreatment improved the Magnefite pulping of heartwood chips. The pretreatment using borax solution also showed some improvement, but less than that produced by water alone. This effect may have been caused by low penetration of borax into the chips, as judged by recovery of pretreatment liquor. Sodium hydroxide solution, under conditions tried, reduced pulp strength and increased the permanganate number. In the trial pre-

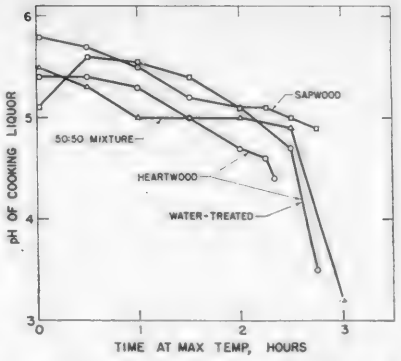

Fig. 1.—Relationship of heating time to acidity when cooking sapwood, heartwood, and mixed chips with 14 percent combined sulfur dioxide.

treatment of sapwood chips with hot water, differences from the control cook were not great enough to establish its value.

Nature of improvement produced by pretreatment was not clearly evaluated in the trials. Extraction of some heartwood constituents appeared to reduce catalytic breakdown of cooking liquor and produced more cooking action on pretreated chips. Any effect of pretreatment on permeability of chips to cooking liquor could not be established from these trials. An indicator of permeability is the amount of screenings in the pulp, which also is influenced by degree of cooking. Further study is underway to establish effect of pretreatment on permeability separately from its effect on catalytic breakdown of the cooking liquor.

Values for strength of pulp shown in Table 2 indicate that the Magnefite-processed Douglas-fir pulps compared favorably to Tappi Reference Standard A, a bleached sulfite pulp from West Coast woods. Although data for kraft pulp were not available from this sample of wood, from trials in the past on Douglas-fir, a kraft pulp would be expected to have somewhat higher Mullen (*ca.* 125% Mullen) and substantially higher tear (*ca.* 235% tear). Heartwood pulps had slightly higher Mullen values than did those from sapwood or a mixture of sapwood and heartwood, possibly because of the difference in springwood content shown in Table 1.

Yield values shown in Table 2 were higher than would be expected from either kraft or sulfite pulps. Although brightness values were low by sulfite standards, the permanganate numbers indicated that they could be bleached at reasonable cost.

Conclusions

1. Since considerable variation in pulping results are attributable to raw material, heartwood and springwood content and permeability of the wood should be considered in pulping Douglas-fir, particularly by the Magnefite or acid sulfite processes.

2. Development of optimum conditions for Magnefite pulping of oDuglas-fir requires further study of the relationship of pulp quality to liquor pH, liquor concentration, cooking time and cooking temperature, and the effect of wood variation on these relationships.

3. Despite the uncertainties of any limited study, Magnefite pulp appears to have promise for utilization of chips from Douglas-fir residue. Magnefite Douglas-fir pulps are superior to acid sulfite pulps both in strength and in yield and the recovery aspect offers an additional advantage. Although strength is lower than for Douglas-fir kraft pulps, the yield is higher, and capital and operating costs lower. Also, there is no problem of odor control.

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Characteristics of Annual Rings in Relation to Wood Quality[1]

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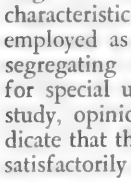
Specific gravity of wood did not invariably increase from pith to bark, but appeared to vary in relation to variations in width of annual rings. Thus ring width is a useful guide to properties of the wood.

OF ALL MEASURABLE PROPERTIES of wood by which technologists judge its quality or particular usefulness, basic density or specific gravity undoubtedly rates first place. Simply determined without elaborate equipment, specific gravity provides a reliable guide to many important properties of wood and, in the absence of other actual test data, can be employed with considered limits of accuracy to indicate mechanical strength, hardness, shrinkage, and other associated properties.

Variation in specific gravity of wood, particularly of important softwood species, has been of interest for many years, during which considerable literature on this subject has been published. A good bibliography was included in a recent Yale University Bulletin by Philip Larson (6)[3]. It is apparent that particular emphasis has been placed on the relation between specific gravity and width of annual rings or other significant anatomical characteristics of wood that might be employed as a guide by inspectors in segregating material of high density for special uses. In spite of extensive study, opinions recently expressed indicate that the subject has not yet been satisfactorily resolved.

The tendency to associate high specific gravity with narrow growth rings in certain softwood timbers has been widely prevalent for many years. Although agreement with this point of view has not been unanimous, the inverse relationship between specific gravity and width of annual rings has been widely accepted, and minimum standards of quality, established on the basis of 'rings per inch", have been employed in the segregation of structural-grade timbers that command premium prices in the lumber market. Information concerning the relation between specific gravity and the rate of growth has also been employed by foresters as a guide to appropriate silvicultural treatment of softwood stands in order to produce suitable material for particular end products.



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In early studies reported on North American species, Hale and co-workers (4, 5) observed a tendency for wood of Eastern Canadian spruces and balsam fir to be high in specific gravity when the rate of growth was slow. The authors state (5) that "with consideration for the aberrations that are explainable on account of youth or old age or the presence of compression-wood, the rate of growth is the most important character that can be recognized for its effect on the density of the species studied".

In regard to species with prominent, contrasting springwood and summerwood, such as Douglas-fir and red pine, Hale and Brophy (3) observed that wood of maximum density was likely to be associated with moderate rates of growth; wood with relatively wide or relatively narrow rings was usually somewhat lighter. These results were subsequently confirmed by Rochester (9) and Trendelenburg (11).

Disagreement with the importance of growth rate did not disappear, however, and in recent years attempts to relate variation in specific gravity to other factors (particularly distance from the pith counted in annual rings) have been reported. The theory that specific gravity of wood tends to increase with distance from the pith regardless of the rate of growth was revived by Turnbull (12, 13) in connection with studies of the growth of young exotic pines in South African plantations. He explains that "the whole misconception regarding the effect of rate of growth, so far, at least as concerns pines, has arisen from the coincidence under normal silvicultural treatment of the radial density and the rate of growth patterns which are causally unrelated". Absence of any important relation between ring width and specific gravity in wood of the same "age" was subsequently implied by other investigators (6, 8, 10, 14). Some confusion might be associated with the use of the word "age" by a number of writers—apparently intended to mean distance from the pith measured in numbers of annual rings.

Papers emphasizing the dominant importance of ring width have been published recently by Aldridge and Hudson (1, 2), who demonstrate its relation to specific gravity in wood of European spruce.

Some of the apparent controversy indicated in the literature may be related to differences in the species studied by different investigators, a situation that is necessarily aggravated if authors generalize about softwoods as a group. Other important sources of discrepancy include confounding of variable factors and failure to recognize compression wood.

Studies reported in this paper were conducted as a part of the research program of the Ottawa Laboratory, Forest Products Laboratories of Canada. Variation in specific gravity of the wood of white spruce was observed in relation to the width of annual rings and distance from the pith in an attempt to reconcile, if possible, conflicting views on this subject.

[1] Based on an MS thesis at the State University of N. Y., College of Forestry, Syracuse University. Revised version for publication received Nov. 24, 1960.

[2] The Forest Products Laboratories of Canada are a division of the Department of Forestry.

[3] Numbers in parentheses refer to the Literature Cited at the end of this paper.

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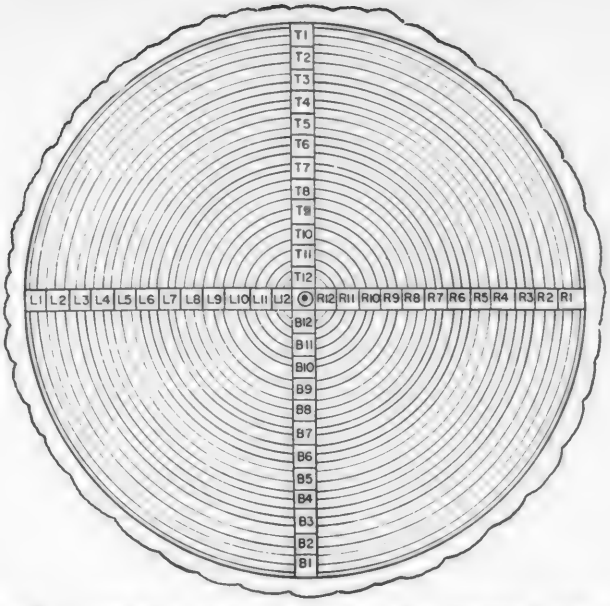

Fig. 1.—Diagram showing the position of test specimens in discs.

Test Material and Method of Testing

Material for this study was obtained in the form of complete discs, about 10 inches in thickness along the grain, cut from each end of 15 white spruce logs selected principally for veneer production. The logs were 13 feet long and originated from trees of fairly large diameter that grew on a uniform bottom-land site near the Peace River in Wood Buffalo National Park, Alberta. Since second 13-foot logs were mixed with butt logs in the material received, the discs could be classified into three height levels as stump, 13-foot level, and 26- foot level. Only one pair of the logs appeared to be adjoining sections from the same tree.

After appropriate anatomical data were recorded for discs in the green condition, the locations of small specimens (approx. one inch cubes) for specific gravity tests were marked along four radii in Fig. 1. These radial strips were positioned at 90° intervals around the discs, although obvious areas of compression wood were avoided as far as possible. An average rate of growth (in rings per inch) for each small specimen was determined from a ring count along each radial strip. In addition, the small specimens were classified according to their distance from the pith in annual rings.

The basic specific gravity (dry weight and green volume basis) was determined for each specimen by immersion in mercury at room temperature and drying to constant weight in a laboratory oven. Although all of the specimens were tested, data from any that contained resin pockets, knots, compression wood, or other abnormalities were necessarily rejected from the analysis based on clear, normal wood. The observations recorded on such clear specimens are shown in Table 1, which contains the mean values of specific gravity for specimens of each combination of growth rate and distance from the pith.

Variation in Specific Gravity Within Individual Stems

Plots of specific gravity on distance from the pith were prepared from data individually summarized for each of 15 discs (one from each log) to observe whether any common significant trend might appear in the radial density patterns for the different stems. Some of these graphs (Fig. 2–4) are shown to demonstrate that a radial gradient in density like that reported for certain other species (6, 7, 10, 13), did not occur consistently in this material. Although specific gravity of wood tends to increase toward the bark on a number of cross-sections, it remains relatively unchanged on others and on some even shows significant "down and up" fluctuations.

Subsequent insertion of the patterns of radial variation in the rate of growth on the same graphs with the specific gravity data by the addition of "rings per inch" as a second ordinate generally indicated that patterns of increasing specific gravity outward from the pith were accompanied by patterns of decreasing ring width. In this respect, an association between the radial patterns of variation in ring width and specific gravity was evident for most of the discs.

Smoothed transverse surfaces of radial strips from three discs are shown in Fig. 5, which illustrates some of the variety in radial growth patterns encountered. The location of each radial one-inch test specimen with respective data on specific gravity are indicated along each radius.

Perhaps the most common pattern of growth, decreasing width of annual rings and increasing density of wood

Table 1.—SPECIFIC GRAVITY DATA FOR CLEAR NORMAL SPECIMENS

Distance from the pith (Ann. rings)	Rate of growth (r.p.i.)										
	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–50	51–60	61–70	71+
5	0.312 1	0.342 1	0.330 1								
10											
15	.312 9	.326 7	.321 2								
25	.296 13	.313 6	.298 1				0.370 1				
35	.285 7	.317 22	.316 8	0.329 1		0.372 2	.394 2				
50	.282 5	.312 28	.326 16	.337 12	0.335 1			0.382 1			
70	.354 1	.319 17	.321 18	.341 16	.342 3					0.390 1	0.371 2
90	.338 2	.324 7	.329 7	.334 12	.339 2	.363 6	.361 3	.361 4		.388 1	.401 2
110	.322 3	.337 11	.310 4	.341 6	.334 2	.345 6	.336 2	.365 1			
130	.335 1	.320 5	.323 4	.343 10	.348 3	.356 4	.360 2	.373 2	.360 3		.385 3
150	.358 1	.333 6	.329 4	.338 10	.352 7	.322 1	.333 1	.368 5	.354 9	.351 2	
170	.345 2	.339 4	.333 5	.346 11	.367 2			.364 1			
200	.320 2	.324 7	.339 8	.337 10	.327 4	.343 5	.359 3	.360 5	.342 6	.348 2	
240			.353 3	.353 5	.347 4	.352 3	.364 2	.341 7	.343 3	.358 1	
280				.354 1		.336 1			.363 4	.369 2	.365 2

Whole numbers shown beneath the mean values of specific gravity indicate the number of individual observations represented by the mean.

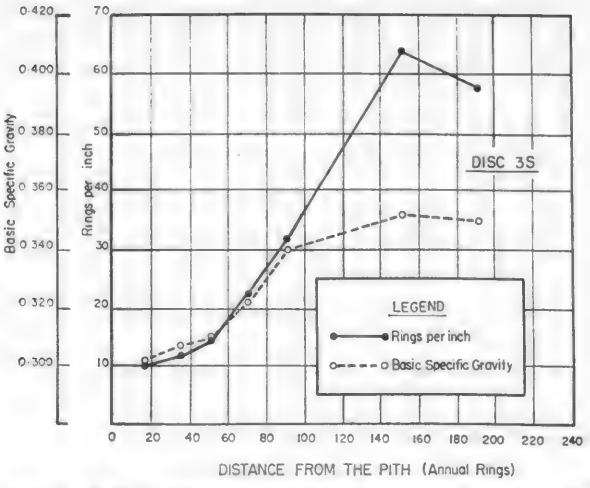

Fig. 2.—Radial density and rate of growth patterns characteristic of stems in which the width of annual rings decreases outward from the pith.

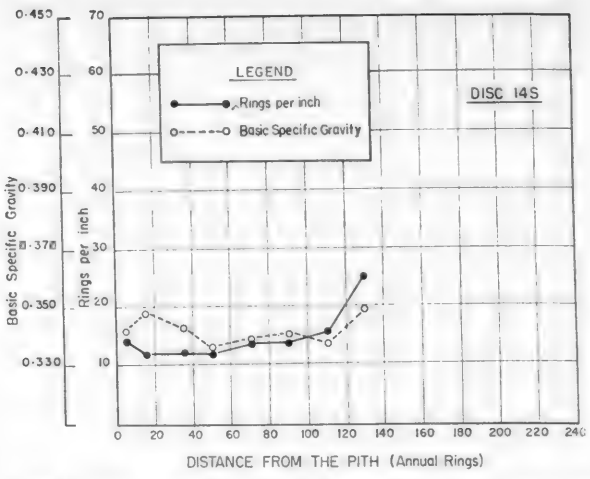

Fig. 3.—Radial density and rate of growth patterns characteristic of stems with relatively little change in the width of annual rings outward from the pith.

toward the bark, is illustrated in Fig. 5A. The outermost sample of this radius appears to be an example of the abnormally light-weight wood sometimes laid down by trees in relatively old age (5). The 11-inch radius shown in Fig. 5B was cut from a disc characterized by annual rings (almost 150) of particularly uniform width. Test specimens from this disc demonstrate that wood near the center of the tree may be as dense as wood of similar ring width formed further out. The radial strip shown in Fig 5C originated from a disc containing an area of very narrow growth rings. Even though these narrow rings occur within a few inches of the central pith, however, the wood is of a maximum density that is not attained in any of the outer wood subsequently formed.

Combined Data From All Stems

To observe any relation between specific gravity and either (a) distance from the pith or (b) width of annual rings, the data for all test specimens were grouped according to combinations of four rate-of-growth and four distance-from-the-pith class designations as shown in Table 2. By assembling the data in this manner, it was possible to compute correlations between specific gravity and distance from the pith for material of comparable rates of growth. Correlations between specific gravity and the rate of growth could also be conveniently determined for material of comparable distances (counted in annual rings) from the pith.

Specific Gravity and Distance from the Pith: Regressions of basic specific gravity on distance from the pith, computed separately for each of the four rate-of-growth classes, have been summarized in Table 3. Plots of the linear regression estimates (Fig. 6) illustrate that specific gravity tends to increase in successive growth rings from the pith only in material with less than about 25 rings per inch. In relatively narrow-ringed specimens the trend is reversed. Furthermore, for specimens of comparable ring width, the computations indicate that generally less than 10 percent of the variation in specific gravity can be associated with variation in distance from the pith. It is evident, therefore, that distance from the pith does not provide a particularly useful basis for predicting relative density in the white spruce test material.

Rate of Growth and Specific Gravity: The regression data for specific gravity on rate of growth are summarized in Table 4. Separate regression estimates are shown for specimens in four classes by distance from the pith. It is interesting to note that all of the correlations are significant, and all have positive slopes. Plotted linear regressions in Fig. 7 illustrate that the inner groups of specimens show a better correlation between rate of growth and specific gravity than do the outer ones. The data indicate that about 30 to 40 percent of the variation in specific gravity of specimens inside the 120th ring can be associated with vari-

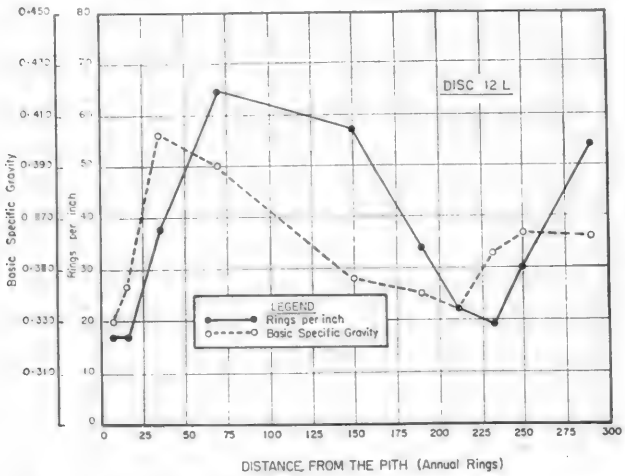

Fig. 4—Radial density and rate of growth patterns characteristic of stems in which the width of annual rings fluctuates on the cross-section.

Table 2.—MEAN SPECIFIC GRAVITY OF SPECIMENS IN COMBINATIONS OF FOUR GROWTH-RATE AND DISTANCE-FROM-THE-PITH CLASS DESIGNATIONS

Distance from the pith (Annual rings)	Rate of growth (r.p.i.)			
	6–15	16–25	26–40	41–85
Up to 60	0.309 99	0.327 41	0.373 6	0.382 1
60–120	.327 41	.331 63	.349 24	.375 11
120–180	.334 19	.338 44	.352 20	.363 25
180 and over	.323 9	.343 27	.346 22	.351 32

Table 3.—REGRESSION ANALYSIS OF SPECIFIC GRAVITY ON DISTANCE FROM THE PITH.

Rate of growth (r.p.i.)	Regression estimate	Std. dev. from regr.	Correl. coeff.	Signif. level
6–15	$\hat{Y}=0.306+0.00016X$	±0.0248	+0.313	1%
16–25	$\hat{Y}=.322+.0001X$	± .0195	+ .307	1%
26–40	$\hat{Y}=.361-.00007X$	± .0198	— .224	Not sig.
41+	$\hat{Y}=.382-.00012X$	± .0198	— .367	1%

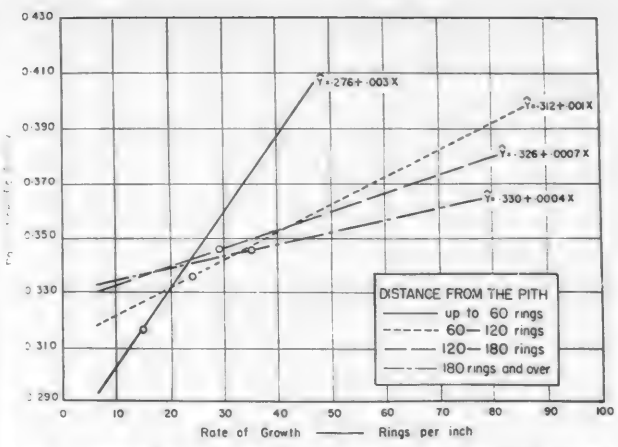

Fig. 6.—Relation between basic specific gravity and distance from the pith in specimens of different ring width.

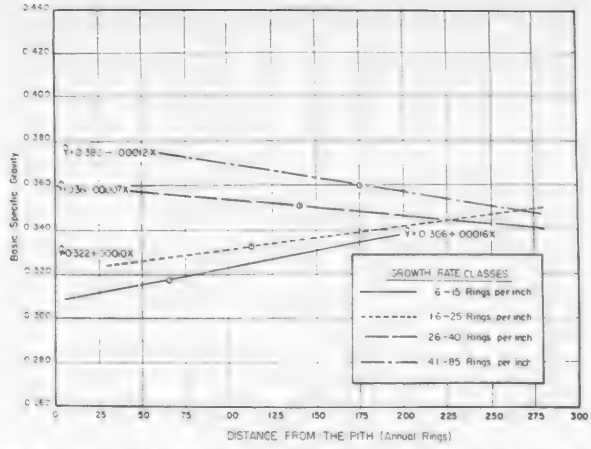
GROWTH RATE CLASSES
6 - 15 Rings per inch
16 - 25 Rings per inch
26 - 40 Rings per inch
41 - 85 Rings per inch
Basic Specific Gravity
DISTANCE FROM THE PITH (Annual Rings)

Fig. 7.—Relation between basic specific gravity and rate of growth in specimens at various distance from the pith.

ation in the rate of growth. Intersections of the regression lines in Fig. 7 at about 20 to 30 r.p.i. relates to the reversal in slope of the specific gravity versus distance from the pith regressions.

In an attempt to define the relation between growth rate and specific gravity more accurately, regression estimates were computed in the form of second degree polynomials by including the quadratic term for ring width. Plotted curves by this method, however, were only slightly concave downward and were otherwise very similar to the linear regression estimates of Fig. 7. The correlation coefficients were increased only slightly, and tests for curvilinearity of regression, that is, significance of departure from linear regression, indicated lack of significance at the five percent level for all four curves.

Photomicrographic Illustration of Results

White spruce, like other conifers of northern temperate latitudes, is characterized by a seasonal pattern of growth in which a springwood or earlywood zone consisting of relatively thin-walled cells with large lumina is formed early in the growing season followed by a summerwood or latewood zone in which the cells have relatively thick walls and small lumina. In view of the high proportion of cell-wall material and, therefore, higher specific gravity of the summerwood bands, the relative width of these bands (that is, the proportion of summerwood tissue) is an important consideration in the specific gravity of gross wood.

Since the proportion of summerwood can provide a visible indication of the relative density of different specimens of wood of the same species, photomicrographs (at low magnification) of transverse sections of a number of test specimens are presented in Figs 8, 9, and 10 to illustrate the results observed in these investigations.

Relatively narrow-ringed specimens from the inner zone (within a few inches of the pith) of two different discs are shown in Figs 8A and 8C. For comparison with these, Figs. 8B and 8D show considerably faster-grown samples from further out (nearer the bark) in the same discs. The higher summerwood content of the narrow-ringed inner specimens illustrates the tendency for high specific gravity to be associated with relatively slow rates of growth, and demonstrates that wood near the center of

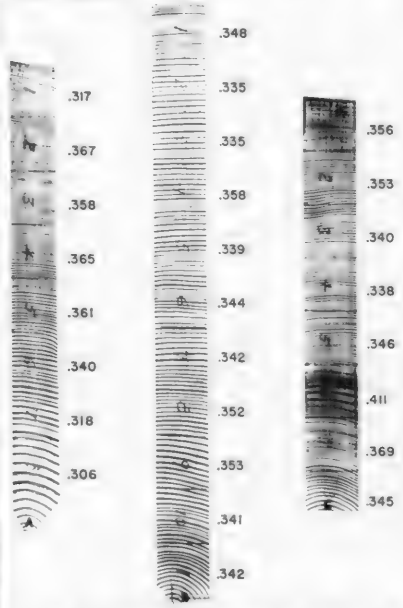

Fig. 5.—Smoothed transverse surfaces of test strips show typical radial growth patterns observed. Positions of one-inch test specimens with respective data on specific gravity are indicated along the radii.

Fig. 8.—Transverse sections of white spruce test specimens demonstrate the tendency for wood with narrow growth rings to have high summerwood content and specific gravity.

	A	B	C	D
Rings from pith	50	102	62	165
Growth rate (r.p.i.)	48	9	78	19
Basic S.G.	0.408	0.314	0.406	0.339

Table 4.—REGRESSION ANALYSIS OF SPECIFIC GRAVITY ON RATE OF GROWTH

Distance from the pith (Ann. rings)	Regression estimate	Std. dev. from regr.	Correl. Coeff.	Signif. level percent
0- 60	$\hat{Y}=0.276+0.003X$	±0.0214	+0.650	1
60-120	$\hat{Y}=.312+.001X$	± .0218	+ .554	1
120-180	$\hat{Y}=.326+.0007X$	± .0195	+ .499	1
180+	$\hat{Y}=.330+.0004X$	± .0170	+ .400	1

the tree is not invariably lighter in weight than wood formed further out.

Fig. 9A shows a section of wood from just inside the bark of a disc containing nearly 250 annual rings, while the section in Fig. 9B shows wood of comparable growth rate from an inner region of the same disc. The lower summerwood content and specific gravity of the outer specimen (Fig. 9A) illustrates that wood near the outside of relatively old stems may tend to be abnormally light in weight for its rate of growth.

Specimens of comparable growth rate and distance from the pith, but with different summerwood content and specific gravity, are shown in Fig. 10 to illustrate that other factors may also be involved in specific gravity variation in the test material. In specimens from different stems, differences in specific gravity associated with genetic constitution or differences in conditions of growth for the different trees may be significant and may, therefore, tend to confuse any relation between specific gravity and rate of growth or other variables under investigation.

Summary

Variation in specific gravity of wood was observed in relation to rate of growth and distance from the pith (counted in annual rings) in 15 relatively large white spruce veneer logs. A tendency for high specific gravity of wood to be associated with narrow growth rings was evident in graphic illustrations of the radial trends of variation in ring width and specific gravity on individual cross-sections. A tendency for specific gravity to increase outward from the center of the tree, independent of variation in the rate of growth, was not observed.

Analysis of combined data from all stems indicated that correlation between specific gravity and distance from the pith accounted for less than 10 percent of the observed variation in specific gravity.

Consistent positive correlation between growth rate (r.p.i.) and specific gravity demonstrates the dominant importance of ring width. Over 40 percent of observed variation in specific gravity could be related to variation in ring width for specimens inside the 60th ring. Reduced correlation in the outer specimens may be related to the tendency for wood near the outside of relatively old trees to be exceptionally light in weight for its rate of growth.

In examining test material from different stems, differences in conditions of growth or genetic constitution of trees may account for some of the variation in specific gravity that could not be related to the observed characteristics of annual rings. Nevertheless, the investigations carried out have demonstrated a consistent significant relation between ring width and specific gravity, which indicates the usefulness of ring width as a readily observable guide to specific gravity and other important properties of the material examined.

Fig. 9.—Transverse sections of white spruce test specimens demonstrate the tendency for wood near the outside of relatively old trees to be lower in summerwood content and specific gravity than wood of similar ring width nearer the center.

	A	B
Ring from pith	225	110
Growth rate (r.p.i.)	44	42
Basic S.G.	0.313	0.348

Fig. 10.—Transverse sections of white spruce test specimens demonstrate differences in summerwood content and specific gravity in wood of comparable growth rate and distance from the pith originating from different stems.

	A	B
Rings from pith	115	95
Growth rate (r.p.i.)	13	12
Basic S. G.	0.281	0.332

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Natural Decay Resistance of Alerce[1]

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ALERCE, *Fitzroya cupressoides* (Molina) Johnston, is considered one of the finest timber species of Chile (2[3]), and it occurs in extensive, pure, old-growth stands. The material has not been produced in quantity for export because of the lack of access roads. It is reportedly comparable to redwood in several characteristics, including weight, color, straightness of grain, large size, and good finish-holding properties. Its service reputation for durability in boats, floors, shingles, poles, troughs, and vats (2, 4, and 5) is excellent in South America. The question arises of how alerce heartwood, although recognized as one of the more durable Chilean species, might be classed for decay resistance according to ratings commonly applied to domestic woods in the United States. The investigation reported here was made to provide information on this point as determined by standard laboratory tests.

Procedure

In order to take into account such variation in decay resistance as may exist among stocks from different trees of the species, heartwood samples from 12 alerce trees were tested. The testing was done by the soil-block method, using two prominent test fungi: *Poria monticola* (Madison 698) and *Lenzites trabea* (Madison 617). The results obtained with *P. monticola* are considered to depict the comparative resistance of wood exposed in ground contact, while the second fungus, *L. trabea,* is thought to have value particularly for estimating the relative resistance of materials exposed above ground. Normally, *P. monticola* causes more decay in test blocks than *L. trabea* when the wood being tested has moderate or greater decay resistance.

The soil-block tests were made according to procedures used at the Forest Products Laboratory for several years in testing the natural decay resistance of various native woods (3 and 6). Except for a difference in block size and for steps related to preservative treatment, the method of testing is similar to the standard adopted by the American Society for Testing Materials for evaluating wood preservatives (ASTM Designation D1413–56T) (1). Specimens, 1 by 1 by ⅜ inch (grain direction), were exposed for 12 weeks to pure cultures of the test fungi. Percentage of weight losses in the specimens from decay were calculated from conditioned, air-dry weights taken before and after the exposure. The wood from each tree was appraised by six replicate tests for resistance to *P. monticola* and by three for resistance to *L. trabea.*

In soil-block tests with two standard test fungi, alerce heartwood was rated "decay resistant." The tests show the Chilean species to be generally less durable than redwood and western redcedar, which are classed as "very resistant."

Using the average percent weight loss, the class of decay resistance of the tested material with respect to the respective fungi was established on the following basis:

Decay Resistance Class	Average Percent Weight Loss
Very resistant	0–10
Resistant	11–24
Moderately resistant	25–44
Nonresistant	45+

This system of classification has proved satisfactory in the past by giving a rating to familiar woods that is generally in close agreement with the reputation of the wood for durability in service. For example, among coniferous woods, the heartwoods of western redcedar and redwood were ranked by soil-block testing as "very resistant," while Douglas-fir and western larch heartwood fell in the "moderately resistant" class.

In addition to testing for overall decay resistance, characteristics of alerce that might be correlated with variability in decay resistance were taken into account. These characteristics were: diameter of the tree bole at the point sampled (estimated from ring curvature), growth rate of the wood comprising the test blocks (rings per inch), specific gravity, and wood color.

Results

Table 1 shows the data available for each sample arranged in descending order of decay resistance to *P. monticola.* The average weight losses in samples of the respective trees decayed by *P. monticola* ranged from 9 to 33 percent, and the average loss for all trees was 20 percent. The corresponding losses with *L. trabea* as the test fungus were 3 to 20 percent among individual trees, with an overall average of 11 percent.

On the basis of the samples tested, it would appear that alerce heartwood should not be classed in general as "very resistant," with such woods as redwood and western redcedar, however, it would be rated as "resistant." Wood of a high percentage of individual trees, however, may be very resistant to many common destructive fungi, as indicated by the fact that specimens from 7 of 12 trees were highly resistant to *L. trabea.* The range of decay resistance in the tested samples (Table 1) appears to be less than is frequently encountered in other species of the same class of decay resistance. With the limited sample of material available, no correlation of practical significance could be found between

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[1] A contributed paper approved for publication January 1960.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Numbers in parentheses refer to Literature Cited at the end of this article.

Table 1.—WEIGHT LOSS CAUSED BY DECAY AND ASSOCIATED DATA FOR HEARTWOOD SAMPLES OF THE 12 TESTED ALERCE TREES

Tree	Estimated Tree Diameter Where Sampled Inches	Specific Gravity of Sample	Rings Per Inch in Sample	Average Weight Loss	
				P. monticola[1] Percent	L. trabea[2] Percent
7	16	0.46	68	9	3
8	14	.39	74	13	4
2	14	.35	61	14	4
3	24	.38	188	15	6
5	18	.41	43	15	6
1	20	.42	38	18	16
4	12	.41	58	19	9
6	14	.45	20	21	9
12	12	.36	68	27	20
11	24	.34	58	28	17
9	12	.35	54	31	19
10	11	.33	37	33	19
Average		0.39	64	20	11

[1]Six replicate blocks were used to determine the average precent weight losses shown.
[2]Three replicate blocks were used to determine the average percent weight losses shown.

decay resistance and tree site, specific gravity, rings per inch, and wood color that would be of practical value in selecting or distinguishing the more durable logs or lumber. The sample boards were largely flat-grained and consequently afforded no chance to check the radial variations in decay resistance within trees.

Summary and Conclusions

Laboratory tests of decay resistance were made on samples from 12 alerce trees, using two standard test fungi with the soil-block test. On the basis of these tests, alerce heartwood may be classed as a "resistant" wood. The species would thus be somewhat less durable generally than redwood and western redcedar, which are classed as "very resistant." But for above-ground use, such as siding, important practical differences in service would seem unlikely to occur. Factors other than the differences in decay resistance would probably be more important in a choice between these species where the exposure does not involve ground contact.

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Preservative Action of Bound Copper and Zinc[1]

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THE ABILITY OF WOOD to bind toxic cations has led to a number of proposals for preserving wood that utilize this property. Ripley–Duggan (14)[2] has suggested the use of copper acetate as a wood preservative in view of the relatively large non-leachable retention of copper metal resulting from ion-exchange with the hydroxyl and carboxyl groups that occur naturally in wood. Kruckeberg (10) speculates that heavy metal ions adsorbed by wood might be effective against marine borers. A process for treating wood with copper formate to form copper complexes (16) was claimed to be effective against fungi, termites, and marine borers. The object of the work reported here was to determine whether such bound cations retain their toxicity.

In contrast to its behavior with copper acetate, wood impregnated with copper sulfate loses its copper rapidly on leaching. Baechler (2) has shown that the copper content of wood impregnated with copper sulfate was reduced from 1.03 to 0.089 percent during five days of leaching. A comparison of the decay resistance of wood impregnated with copper sulfate and with copper acetate should show whether the bound copper has retained its toxicity. This comparison has now been made, as well as a similar comparison utilizing zinc chloride and zinc acetate.

It is generally accepted that, in the absence of a toxic anion such as arsenate, the toxicity of inorganic salts resides in the cation and is proportional to the content of toxic cation. This relationship is illustrated for three zinc salts in Table 1. Although the amount of salt effective against "Madison 517" in agar is different for each compound, the actual zinc concentration in the agar is remarkably constant when it is considered that the data were collected by three different investigators over a span of 22 years. It would be expected, therefore, that at the same copper content, copper sulfate and copper acetate should be equally effective against fungi. This correlation has been shown to be true for zinc chloride and zinc acetate in Table 1.

The actual location of bound copper in the wood is open to question. That introduced by copper formate was assigned to the amorphous regions of the cellulose (1). Belford and coworkers (5) present evidence for a copper–cellulose complex also, but believe it to be different from that introduced by copper formate. On the other hand, Bayley (4) suggests that the complexes are predominantly the product of the interaction of the metal ions with acidic, cation-binding non-cellulose constituents (pectins, uronic acids, lignin) of the wood. For the present discussion, the actual location is not important because of the close

[1] A contributed paper, received Aug. 1, 1960.
[2] Numbers in parentheses refer to the Literature Cited at the end of this paper.

Binding copper and zinc ions to wood structure with acetates makes them less available for toxic action on fungi. When these metals are supplied as sulfates or chlorides, lower retentions are needed for effective protection.

ssociation of these non-cellulosic naterials with the cellulose of the ood.

Experimental

Although the toxic limits in agar nd soil-block threshold values for oth copper sulfate and zinc chloride gainst many fungi have been reported in the literature, it was considered desirable to test these compounds over a range of retentions against the same strains of fungi as the corresponding acetates.

Southern yellow pine (*Pinus* spp.) sapwood cubes, ¾ inch on each side, were impregnated with 2, 1, 0.5, 0.25 and 0.12 percent solutions of copper sulfate and zinc chloride. Retentions of salt were calculated from solution retentions and concentration. Control blocks were impregnated with distilled water. After drying and without leaching, the treated blocks and controls were exposed to four species of wood-destroying fungi by the standard ASTM method D 1413–56T (Soil Block Test).

For the copper and zinc acetate treatments, only one impregnation was made with strong solutions to ensure maximum binding of the cations. A 7 percent copper acetate solution and a 10 percent zinc acetate solution were used. After they were dried, half the blocks treated with each solution were subjected to a weathering cycle for 87 days. For 40 percent of the 72-minute cycle, the blocks were immersed in running water. For the remainder of the cycle they were exposed to ultra-violet radiation while being dried by a stream of air. Then the weathered and unweathered blocks were exposed to the four species of fungi. Chemical analyses were performed on representative blocks before and after weathering to determine copper and zinc contents.

In a related study, blocks were treated with 1.2 and 0.6 percent copper formate solutions and with a 1.5 percent copper acetate solution. Some of the copper-formate-treated blocks were cured at 125° C and some were air-dried. The copper-acetate-treated blocks were air-dried. Half the blocks from each treatment were weathered for 30 days as above. Samples from each treatment, weathered and unweathered, were analyzed for copper. The remaining blocks were then exposed to four species of fungi in the soil-block test.

Results

The retentions of salts, the fungi used, and the weight loss on exposure to these fungi for blocks treated with zinc chloride, zinc acetate, copper sulfate, copper acetate, and copper formate are presented in Tables 2 through 6.

Richards (13) has reported the threshold retention of zinc chloride in the soil-block test on unweathered blocks to be 0.50 lb./cu. ft. against Madison 698 and 0.25 lb./cu. ft. against Madison 617. The weight losses in Table 2 are in agreement with these thresholds, with severe weight loss at 0.4 lb./cu. ft. falling off to slight weight loss at 0.9 lb/cu. ft. for Madison 698 and similar behavior between 0.2 and 0.4 lb./cu. ft. for Madison 617.

Examination of Table 3 shows severe attack by Madison 698 and marked visible attack by Madison 515 on unleached blocks treated with zinc acetate to a zinc content of 3.3 percent. Zinc chloride protected against these organisms at much lower levels. After they were leached, all the zinc-acetate-treated blocks were attacked despite a zinc content of 0.68 percent, which was adequate to protect against all but Madison 698 when the zinc was introduced as zinc chloride.

The toxic limits for copper in the form of copper sulfate have been given for a number of fungi as 0.01 to 0.1 lb./cu. ft. (15). None of the fungi in the present study were included, but Madison 515, 534 and 617 show a similar range (Table 4). A threshold value for Madison 698 is apparently being approached at a retention of about one lb./cu. ft. of copper sulfate or 0.4 lb./cu. ft. as copper metal. This is much higher than values of 0.06 to 0.15 lb./cu. ft. copper as copper naphthenate found for this organism by Duncan (8) and Cowling (7).

The unweathered copper-acetate-treated blocks with a copper content of 2.25 percent were still severely attacked by Madison 698 and showed visible attack by Madison 515 (Table 5). After they were weathered, blocks at a copper content of 1.15 percent were severely attacked by both these organisms. This copper content is much greater than the 0.25 percent copper found adequate for protection against Madison 515 when introduced as copper sulfate.

Table 6 shows that the copper formate treatment provides protection against Madison 534, 617 and 697, in agreement with the original observations of Walton–Smith and coworkers (16). As previously reported by McKnight (11), however, the copper-tolerant *Poria monticola* can still attack wood treated with this material. Whether cured in the oven or air-dried, the weathered and unweathered blocks showed the same resistance to decay or suffered similar attack by Madison 698. Copper acetate also protects the wood when copper formate does, and is ineffective against Madison 698 as is copper formate.

Discussion

It is apparent from these results that lower retentions of copper and zinc as copper sulfate and zinc chloride are needed to protect wood from decay than when copper or zinc acetates are used. Binding the copper and zinc ions to the wood structure by treatment with the acetates makes them less available for toxic interactions with the fungi.

Table 1.—KILLING CONCENTRATION IN AGAR OF ZINC SALTS AGAINST THE FUNGUS "MADISON NO. 517"

Compound	Formula	Killing concentration of compound, % by weight	Killing concentration of zinc, % by weight
Zinc acetate	$Zn(C_2H_3O_2)_2$	0.47(3)	0.17
Zinc chloride	$ZnCl_2$	0.35(12)	0.17
Zinc sulfate (commercial)	$ZnSO_4.7H_2O$	0.65(9)	0.15

Table 2.—WEIGHT LOSS (%) IN SOIL BLOCK TEST OF UNLEACHED BLOCKS IMPREGNATED WITH ZINC CHLORIDE[1]

Retention of $ZnCl_2$ lbs./cu. ft.	Approximate zinc content[2] Weight %	*Coniophora puteana* Madison 515	*Lentinus lepideus* Madison 534	*Lenzites trabea* Madison 617	*Poria monticola* Madison 698
0	0	12.6	31.3	15.6	39.9
0.05	0.08	10.9	30.2	19.6	38.6
0.1	0.15	10.1	25.3	23.1	36.8
0.2	0.30	3.6	10.1	26.0	40.1
0.4	0.61	3.2	3.6	7.2	36.8
0.9	1.37	4.9	4.5	5.5	7.6

[1]Each value is the average of four blocks.
[2]Calculated from retention and average dry weight of blocks.

Table 3.—WEIGHT LOSS (%) IN SOIL BLOCK TEST OF BLOCKS IMPREGNATED WITH ZINC ACETATE[1]

	Retention of $Zn(C_2H_3O_2)_2 \cdot 2H_2O$ lbs./cu. ft.	Zinc content by analysis Weight %	*Coniophora puteana* Madison 515	*Lentinus lepideus* Madison 534	*Lenzites trabea* Madison 617	*Poria monticola* Madison 698
Before leaching	4.6	3.3	4.2[3]	1.7	1.9	29.4
After leaching	0.9[2]	0.68	17.3	1.3[3]	10.3	27.0
Untreated	0	0	24.0	23.4	14.1	33.4

[1]Each value is the average of two blocks except for untreated controls which are average of four.
[2]Calculated as acetate on basis of zinc content, although unlikely zinc present as acetate.
[3]Marked visible attack on surface.

Table 4.—WEIGHT LOSS (%) IN SOIL BLOCK TEST OF UNLEACHED BLOCKS IMPREGNATED WITH COPPER SULFATE[1]

Retention of $CuSO_4$ lbs./cu. ft.	Approximate copper content[2] Weight %	*Coniophora puteana* Madison 515	*Lentinus lepideus* Madison 534	*Lenzites trabea* Madison 617	*Poria monticola* Madison 698
0	0	12.6	31.3	45.6	39.9
0.05	0.06	6.7	20.1	33.9	33.8
0.1	0.12	6.1	6.7	19.9	32.0
0.2	0.25	2.7	2.5	3.6	28.3
0.4	0.50	4.7	3.9	3.6	27.9
0.9	1.13	6.4	6.4	6.4	18.7[3]

[1]Each value is the average of four blocks.
[2]Calculated from retention and average dry weight of blocks.
[3]Two of the four blocks had weight losses below 10 percent.

In their discussion of the adsorption of metal ions on cellulose, Belford and co-workers (6) point out that the drop in pH observed during this adsorption suggests that complexing involves replacement of hydrogen by metal atoms. Under acid conditions, the reaction is reversed and the metal ions are released. They conclude that the complexing is governed by the Law of Mass Action and is dependent upon the pH of the solution, which thereby accounts for the higher copper uptake in copper acetate solutions than in copper sulfate solutions.

The copper and zinc acetates are the salts of a weak acid. When these salts react with the acidic groups naturally occurring in the wood, compounds are formed that are stable to the weak acetic acid liberated. These compounds are not readily ionized by water, so the copper and zinc are present in a non-leachable state.

Copper sulfate and zinc chloride, on the other hand, are the salts of strong acids. The hydrochloric and sulfuric acids liberated by double displacement reactions with the acidic groups in the wood are strong enough acids to prevent the insolubilization of copper and zinc by this means. The metal introduced as the salt of a strong acid is free to inhibit the enzyme systems of the fungi, while that introduced into the wood as the acetate is bound to the wood and is less available for preservative action. This is in contrast to the behavior in agar (Table 1), in which toxicity was independent of the character of the anion.

The reason for the much higher tolerance of *Poria monticola* for copper in the form of copper sulfate than in the form of copper naphthenate is obscure. It may involve the ability of the organism to insolubilize the water-soluble form, or may be related to the ability of the oil-soluble copper naphthenate to penetrate a lipid-rich cell wall of the organism. The naphthenic acids themselves are not highly toxic.

Since the copper formate treatment does not provide protection against this fungus, the proposal that decay resistance from this treatment stems from cross-linking is not a satisfactory explanation. It seems more likely that, as with copper acetate, enough copper is bound so that the small percentage which is freed by dissociation is sufficient to be effective against copper-sensitive fungi.

These studies have also shown the greater efficiency of copper compared to zinc in preserving wood against decay.

Table 5.—WEIGHT LOSS (%) IN SOIL BLOCK TEST OF BLOCKS IMPREGNATED WITH COPPER ACETATE[1]

	Retention of $Cu(C_2H_3O_2)_2 \cdot H_2O$ lbs./cu. ft.	Copper content by analysis Weight %	*Coniophora puteana* Madison 515	*Lentinus lepideus* Madison 534	*Lenzites trabea* Madison 617	*Poria monticola* Madison 698
Before leaching	3.3	2.25	2.2[3]	+0.4	0.4	29.4
After leaching	1.7[2]	1.15	14.7	+1.0	0.3	16.4
Untreated	0	0	24.0	23.4	14.1	33.4

[1]Each value is the average of two blocks except for untreated controls which are averages of four.
[2]Calculated as acetate on basis of copper content, although unlikely copper present as acetate.
[3]Marked visible attack on surface.

Table 6.—WEIGHT LOSS (%) IN SOIL BLOCK TEST OF BLOCKS IMPREGNATED WITH COPPER FORMATE OR COPPER ACETATE[1]

Concentration of solution (%)	Compound	Cure conditions	Weathered	Copper by analysis %	Soil block assay: *Lentinus lepideus* Madison 534	*Lenzites trabea* Madison 617	*Polyporus versicolor* Madison 697	*Poria monticola* Madison 698
1.2	Copper formate	125° C for 2 hrs.	No	0.53	0.0	0.0	0.0	13.7
1.2	"	"	Yes	0.57	0.0	0.1	0.2	24.2
0.6	"	"	No	0.33	0.1	0.0	0.0	24.6
0.6	"	"	Yes	0.28	0.9	0.8	0.1	10.7
1.2	"	Air dried	No	0.54	0.4	0.6	0.6	16.6
1.2	"	"	Yes	0.38	0.2	0.5	0.3	19.7
1.5	Copper acetate	"	No	0.72	0.4	0.8	0.8	12.8
1.5	"	"	Yes	0.56	0.1	0.3	0.2	25.2

[1]Based on average of four specimens.

Conclusions

Lower retentions of copper and zinc are needed to protect wood from decay when these metals are supplied as sulfates or chlorides than when copper or zinc acetates are used. Binding the copper and zinc ions to the wood structure by treatment with the acetates makes them less available for toxic interactions with the fungi.

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INFLUENCE OF POSITION IN TREE ON

Recoverable Collapse in Wood[1]

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In 2 ash eucalypts, amount of recoverable collapse varied consistently within a tree, decreasing with increase in height.

THERE ARE SEVERAL REFERENCES in the literature to the variation of shrinkage of timber with position in the tree. Paul and Marts (1)[2] showed that for several southern United States hardwoods there was a general increase in total shrinkage from the bark to the center of the tree. Total shrinkage is defined as combined normal shrinkage and collapse. On the other hand, Kelsey and Bisset (2) investigated the relation between tangential and radial shrinkage from bark to pith at four elevations within one tree of *E. regnans,* and found that shrinkage increased significantly as the number of growth rings from the pith increased. Tiemann (3) observed that California-grown blue gum collapsed more severely in the butt logs than in the top logs. A similar effect was noticed by Elliot and Currie (4) in "ash" eucalypts. Kauman (5) observed during studies on collapse that specimens taken 1½ to 5½ inches beneath the sapwood collapsed more severely in the butt log than in the top log.

In view of the lack of definite information on the variation of shrinkage and collapse with height within a tree, it was decided to examine this subject under the broad program of studies on collapse at present being carried out in the Division of Forest Products, C.S.I.R.O.

The present paper describes the results of an investigation of the influence of position in tree on collapse intensity.

Material

Material was taken from six Victorian grown trees of *E. regnans* approximately 50 years old and 100–120 feet in height. A cross-sectional disc about 7 inches in length along the grain was cut from each of four of the trees at 4, 36, and 68 feet from the ground (Group I), and from the other two trees at 24, 56, and 88 feet (Group II).

The diameters of the discs of both species ranged from 10 to 27 inches.

In addition, segments from two trees of *E. gigantea* were obtained from Southern Tasmania.[3] These trees were approximately 300 years old and 240–250 feet in height. Discs were taken at 7, 30 and 80 feet from the ground in one tree and at 9, 51 and 91 feet from the ground in the other.

Specimens from both species were prepared from the discs by cutting 1-inch quartersawn strips approximately 7 inches long along the grain. These strips extended from bark to pith in width.

From each *E. regnans* tree, eight end-matched 15/16 inch cubes were taken at each height, four from the sapwood and four from the heartwood 3 inches below the bark. All specimens were cut from the same side of the tree to obtain direct comparison between specimens at different elevations.

From each segment of *E. gigantea,* five specimens 2.5 (tangentially) by 1 (radially) by 1 inch (along the grain) were obtained. Each specimen contained both sapwood and heartwood.

All specimens were sealed on the end grain with nitro-cellulose lacquer.

Experimental Procedure and Results

E. regnans. Each 15/16 inch cube was weighed in the green state, and its

[1] A contributed paper, received Dec. 1, 1960. [2] Numbers in parentheses refer to the Literature Cited at the end of this paper.

[3] Collected by Mr. R. L. Newman of Australian Newsprint Mills.

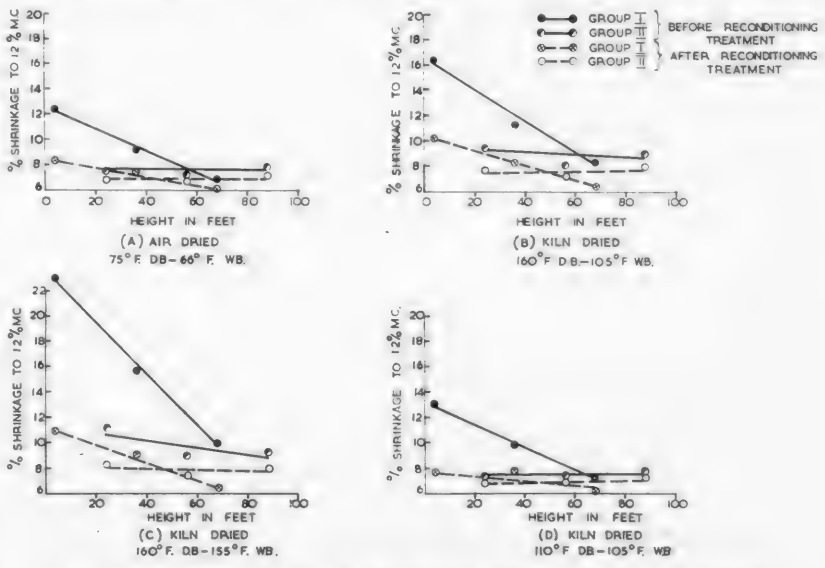

Fig. 1.—Effect of height in tree on total tangential shrinkage of *E. regnans* sapwood.

Table 1.—TREATMENT MEANS FOR *E. GIGANTEA*

Drying conditions		Total shrinkage to 12 percent M.C.					
		Before reconditioning		After reconditioning		Removable collapse	
Dry bulb temp. °F.	Wet bulb temp. °F.	T %	R %	T %	R %	T %	R %
75	66	19.5	6.6	8.1	3.2	11.4	3.4
[1]	[1]	20.8	6.5	9.3	3.4	11.5	3.1
95	10	20.5	7.4	7.7	3.2	12.8	4.2
160	10	30.3	9.8	12.9	4.3	17.4	5.5
160	30	28.3	9.1	10.7	3.4	17.6	5.7

[1]Dried to 25 percent moisture content in a conditioning room operating at 75° F. dry-bulb and 67° F. wet-bulb temperature; then dried for 24 hr. in a kiln at 130° F. dry-bulb and 115° F. wet-bulb temperatures; then further dried to 15 percent moisture content in a kiln at 140° F. dry-bulb and 120° F. wet-bulb temperatures; and finally dried to 12 percent moisture content in the above conditioning room.

Table 2.—HEIGHT MEANS OF *E. GIGANTEA*

Tree no.	Height ft.	Total shrinkage to 12 percent M.C.					
		Before reconditioning		After reconditioning		Removable collapse	
		T %	R %	T %	R %	T %	R %
1	7	33.9	10.6	13.8	3.9	20.1	6.7
	30	25.0	8.2	10.4	4.2	14.6	4.0
	80	20.5	7.3	9.0	3.3	11.5	4.0
2	9	23.7	6.8	9.2	2.8	14.5	4.0
	51	22.8	8.0	7.9	3.3	14.9	4.7
	91	17.3	6.5	8.2	3.6	9.1	2.9

tangential and radial dimensions were measured to an accuracy of 0.1 percent.

One specimen from each elevation and position across the tree was allotted, at random, to each of the four drying conditions. A small laboratory kiln with an air velocity of 200 feet per minute was used for drying at 160° F. dry-bulb temperature with 155° F. and 105° F. wet-bulb temperatures, respectively, and at 110° F. dry-bulb temperature with 105° F. wet-bulb temperature. A conditioning room with natural convection was used for drying at 75° F. dry-bulb and 67° F. wet-bulb temperature.

Kiln drying was continued until the material reached approximately 15 to 20 percent moisture content. The material was then conditioned to equilibrium at 75° F. and a relative humidity of 60 percent. (These conditions correspond to 12 percent equilibrium moisture content in untreated material.) Specimens were then weighed, measured and placed in a steaming chamber for a 2-hour reconditioning treatment, again conditioned to equilibrium as before, and then re-weighed, re-measured, and finally oven dried.

Fig. 1 and 2 show the means of total tangential shrinkage for the two groups of trees at equilibrium before and after reconditioning treatment. The standard deviation of tangential shrinkages in trees of Group I was 2.4 percent before and 1.3 percent after reconditioning, and in Group II 1.3 percent before and 0.9 percent after reconditioning treatments. The total radial shrinkages varied from 4.6 to 11.4 percent before reconditioning and from 3.4 to 5.8 percent after reconditioning treatment. The trends for total radial shrinkage for all drying conditions were similar to those observed with tangential shrinkages.

E. gigantea: One specimen from each disc was allotted, at random, to each of the five drying conditions listed in Table 1. Measurements and weights were taken at the end of each treatment as described above for *E. regnans*.

The results obtained are tabulated as treatment means in Table 1, as means in Table 2.

Discussion and Results

The results for both species show that considerable differences in the recoverable collapse may occur under various drying conditions. It has also been shown that total shrinkage decreased with increase in height in the tree.

As noted before, the *E. regnans* trees were divided into two groups, material from Group I being taken at 4, 36, 68 feet, and from Group II at 24, 56, and 88 feet. The results from Figs. 1 and 2 show clearly that the height effect is reasonably linear for each group of trees, but the gradient for one group is greater than that for the other. The magnitude of the difference depends on the drying condition. In the upper part of the trees, above approximately 60 feet the total shrinkages and removable collapse in the two groups are of similar magnitue, but in the butt logs the removable collapse in Group I is about twice as great as in Group II. No appreciable difference in collapse intensity was obtained between heartwood and sapwood except that in Group II less removable collapse was observed in the sapwood. The results given in Figs. 1 and 2 show that the variation of collapse between groups of trees was more pronounced in the butt logs than in the top logs. Similarly, the effect of temperature on collapse was greatest in the butt logs.

With *E. gigantea,* the results for both trees were in agreement and gave good confirmation of those obtained for *E. regnans*. Total shrinkage and recoverable collapse both tended to be higher in the butt than in the top logs.

From the above it can be concluded that collapse intensity in ash eucalypts decreases with height in the tree, but the amount of variation may differ greatly from tree to tree.

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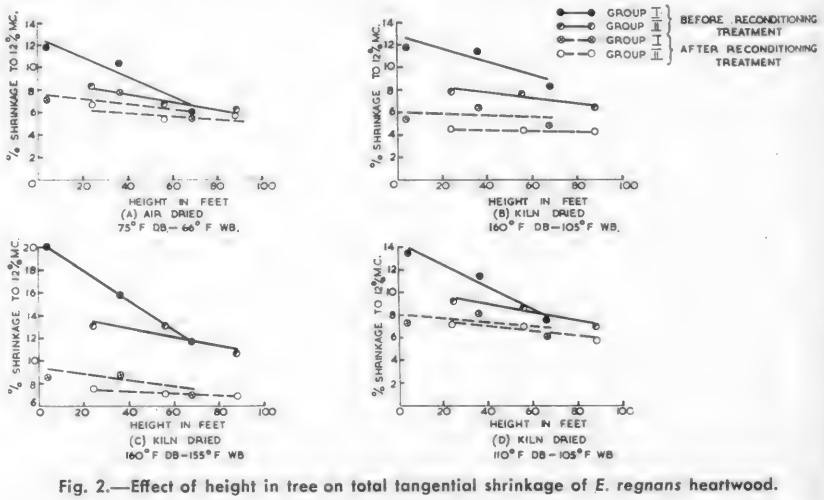

Fig. 2.—Effect of height in tree on total tangential shrinkage of *E. regnans* heartwood.

APPLYING CUMULATIVE FREQUENCY DISTRIBUTION IN

Moisture Control During Kiln Drying[1]

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ONE OF THE BASIC PROBLEMS involved in kiln drying lumber is the estimate of moisture content variation. This moisture variation problem might be thought of as occurring in three stages.

In stage one, the problem of moisture variation is confronted before the actual kiln drying begins, in the sampling of green or air-dried lumber for moisture content. Two objectives usually are involved: one is to determine the initial setting of the kiln controls; the other is to select the so-called sample boards to be used to represent the lumber as kiln drying progresses.

In stage two, the problem of moisture variation is faced during the kiln drying period where, on the basis of measurement of moisture content of the sample boards by the oven method, kiln schedules are progressively changed until the lumber is judged to be ready for removal.

In stage three, the problem of moisture variation again arises in the estimation of moisture content after the kiln charge is pulled, when the lumber is run into the mill for conversion into flooring, dimension products, paneling, and such. Here the question is one of whether the kiln has furnished the mill with lumber of acceptable or unacceptable moisture variation as far as manufacture of the end products is concerned.

The efficiency with which this moisture variation problem is met greatly influences the economics of kiln drying and the manufacturing of lumber products. A wrong guess about moisture-variation patterns of lumber going into a kiln, and changing moisture-variation patterns during kiln drying, could bring about at least three undesirable results.

In the first place, a poor choice of sample boards could be made. Second, the lumber could be damaged through following too severe a kiln schedule on the basis of the wrong guess about initial moisture variation. And third, drying time could be unnecessarily prolonged through selecting too mild a kiln schedule.

The dry kiln operator must know the MC of his lumber and its variation for proper kiln control. Statistical techniques described here may make the job easier.

Also, a wrong guess about moisture-variation patterns existing at the time of pulling the kiln could have further undesirable results. One of these could be the delivery to the mill of improperly dried lumber, with resulting losses in subsequent manufacture of wood products, and also in customer complaints. Another undesirable result could be the sending of the lumber back to the kiln for additional drying, thus increasing production costs.

In fact, it is probably safe to say that moisture variation problems in one form or another are at least partially responsible for the growing success of competitive products in markets that were once held by wood. Since the economics of kiln drying and wood product conversion appear to be so greatly influenced by the problem of moisture variation, it is only logical that the science of statistics, which deals with the subject of variation, would be able to provide some methods and concepts useful in meeting the moisture problem.

It will be the purpose of this article to show how the use of one of these techniques, Frequency Distribution Analysis, might aid in better solving the problem of interpretation and control of moisture variation in kiln drying.

The theory and application of frequency distribution analysis will next be explained, and then the previously mentioned three stages of the dry kiln moisture variation problem will be discussed separately to show how the technique might be usefully applied to each stage.

Frequency Distribution Analysis Theory

A frequency distribution is nothing more than a convenient way to present a group of data for further analysis. The frequency tally is perhaps the most widely recognized form of a frequency distribution. Fig. 1 is an example of a frequency tally on moisture-content readings obtained by the oven method that might be typical of kiln-dried lumber going into the mill. The number of tally marks opposite each moisture-content class simply indicates the number of times the particular moisture content was observed. Thus we see in Fig. 1 that there were 6 readings between 4.5 and 5.5 percent, 14 readings between 5.5 and 6.5 percent, and so on. Fig. 1 also shows a smooth curve superimposed over the tally marks. If a frequency scale is added along the bottom of the diagram, as has been done, the tally marks might be erased, leaving only the smooth curve to represent the variation pattern. Or this frequency curve might be plotted directly without going through the step of recording tally marks.

There are three general characteristics of frequency distributions that are of interest in the evaluation, analysis, and control of variation patterns. These are:

a) some measure of central tendency of the data;
b) some measure of dispersion of the data;
c) general shape of the variation pattern.

[1] A contributed paper, received July 6, 1951. Based on an MS thesis submitted to the University of Tennessee.

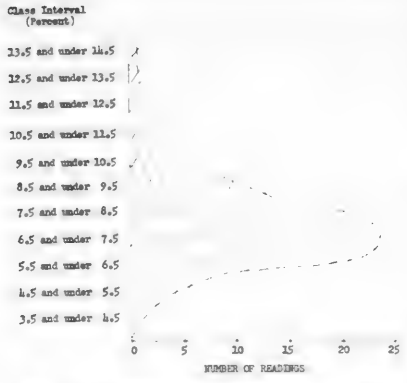

Fig. 1.—Frequency distribution tally of lumber moisture content.

The most commonly used measure of central tendency is the familiar arithmetic average, although the median and the mode are also sometimes used. The standard deviation is the most commonly used measure of dispersion.

Procedures for calculation of averages and standard deviations are described in any text on elementary statistics. These calculations will not be presented here, because the method to be described of applying the frequency distribution analysis is a graphical one, and does not require separate arithmetical calculation of average and standard deviations. This fact will perhaps be welcomed by kiln operators, in view of the amount of record-keeping and sample board weight calculations they are confronted with in the normal routine of kiln drying.

In regard to the third-mentioned characteristic of frequency distribution —the general shape—notice that the frequency curve of lumber moisture content as presented in Fig. 1 is not exactly symmetrical about the average value of 8 percent. The curve trails off in the direction of higher moisture contents or in skewed in that direction. This appears to be a characteristic of lumber moisture-content distributions encountered under practical drying conditions, and is an important factor in the interpretation and application of frequency distribution analysis in the control of moisture variation.

For reasons that will be evident later, it is necessary in applying this graphical procedure that the variation pattern should be changed to a symmetrical one. Fortunately, the variation pattern of lumber moisture content appears to be one of those where this symmetry requirement can be accomplished by changing the vertical scale of moisture content values from an arithmetic scale to a logarithmic scale. This has been done in Fig. 2, and the smooth curve fitted over the tally marks is symmetrical in that the shape of the curve on either side of the average is the same. The curve is also seen to be bell-shaped.

This symmetrical, bell-shaped curve is actually the graphical expression of the mathematical equation of the Normal Law of Variation. This law was discovered in 1773 by Abraham De Moivre when he was working on the solution of certain problems arising with games of chance. Today we know that this Normal Law also describes variation patterns of an amazingly wide number of phenomena of one sort or another in our environment. Examples range all the way from the variation shown by measurements on the basal diameter of egg capsules of marine snails to variation patterns of many quality characteristics in industry.

Fig. 2 is an example of a frequency distribution of a variation pattern presented in what is known as its non-cumulative form. In the applications that will follow, it will be necessary to change from the non-cumulative form to the cumulative form.

Table 1 shows the data conveniently arranged for construction of the cumulative form of the frequency distribution. In the right column of Table 1 the data have been cumulated on a "less than" basis, working from bottom to top. For example, one reading (or 1.3 percent of the total 77 readings) is less than 4.5 percent, and seven readings (or 9.1 percent of the total) are less than 5.5 percent, and so on.

The next step is to plot the data on some especially designed graph paper called log-normal probability paper. This is done in Fig. 3. For example, from Table 1 it can be seen that 9.1 percent of the readings are under 5.5 percent moisture content. This information is next plotted in Fig. 3 as a point located at the intersection of the 5.5 percent moisture content line with the 9.1 percent cumulative percent line. This plotted point used for illustration has been circled in Fig. 3. All the other points are plotted in a similar manner from the cumulative frequency data contained in the right column of Table 1.

Through these points a straight line is drawn on Fig. 3 as shown. This straight line is just another way, in addition to the frequency tally and frequency curve shown in Fig. 2, to represent a variation pattern. The fact that all points fall in a fairly straight line confirms the assumption previously made that the Normal Law does describe moisture variation of lumber when expressed in logarithms. Marked departure of such plotted points from the straight line would indicate that this law for some reason (such as mixing of air-dried and green lumber) did not describe the expected variation pattern.

After the plotting of the straight line on Fig. 3, certain information can be read at a glance about the properties of the variation pattern. For example, one can easily tell that 95 percent of the total moisture content values of the lumber can be expected to fall in a moisture content range of 4.5 to 12.7 percent, and about 35 percent of the lumber could be expected to fall in the 6 to 8 percent moisture content interval. The point of intersection of the straight line representing the frequency distribution with a horizontal line from the 50 percent point on the cumulative percent scale of the log-normal distribution gives an estimate of the average moisture content as about 7.7 percent.

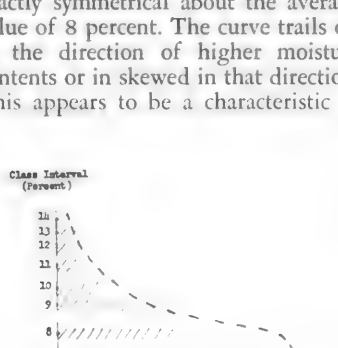

Fig. 2.—Frequency distribution tally of lumber moisture content made symmetrical by plotting the moisture contents on a logarithmic scale.

Table 1.—LUMBER MOISTURE CONTENT DATA OF FIG. 1 ARRANGED FOR CUMULATIVE FREQUENCY TABULATION

Upper limit of successive moisture content class intervals	Cumulative number of readings	Cumulative percent of total readings
Less than 4.5%	1	1.3
Less than 5.5%	7	9.1
Less than 6.5%	21	27.2
Less than 7.5%	43	55.8
Less than 8.5%	55	71.5
Less than 9.5%	67	87.0
Less than 10.5%	71	92.3
Less than 11.5%	73	94.7
Less than 12.5%	74	96.0
Less than 13.5%	76	98.7
Less than 14.5%	77	100.0

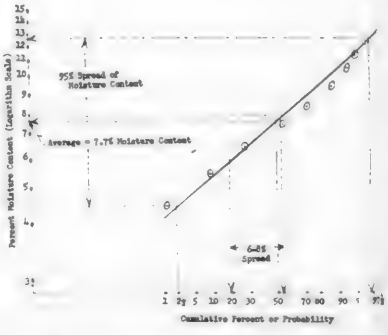

Fig. 3.—Cumulative moisture content plot.

Application of Frequency Distribution Analysis to Moisture Variation Problem of Lumber Going Into the Kiln

In the application of this theory to moisture variation, first consider stage 1 of the total problem, which was previously defined as that part dealt with in the sampling of the green lumber for moisture content.

The two methods used in determining moisture content of lumber are known as the oven method and the moisture-meter method. Both contain measurement errors to some degree, as does any measuring process. Of these two, the oven method is considered to be more accurate than the moisture-meter method. On the other hand, the meter method is easy and rapid, and for these reasons makes possible the taking of larger size samples for moisture content determination. Another disadvantage of moisture meters, particularly the resistance type, is that the moisture range in which the meter may be used with any degree of reliability extends only from about 5 percent to the fiber saturation point, which occurs at about 25 or 30 percent moisture content. Unfortunately, there are occasions when the correct solution to different aspects of the total moisture variation problem requires moisture-meter measurements under 5 percent and over the fiber saturation point.

For example, in the sampling of so-called "90-day lumber" for moisture content as it goes into the kiln, a good percentage of the lumber is sometimes above the 30 percent fiber saturation point.

The situation of supply and demand of this lumber—particularly in the winter months—appears to be such that the industry is forced to tolerate this practice as a necessary evil if one is to have any air-dried lumber at all to kiln dry. Nevertheless, this percent of high-moisture-content lumber mixed in with the air-dried lumber of normal moisture content does add considerably to the problem of sample board selection, and also to the problem of choosing and maintaining optimum kiln schedules.

To illustrate how this problem arises, suppose that six boards had been selected from the kiln charge as it was stacked, to use as sample boards. The moisture contents of six such boards are as follows:

Board number	Moisture content, percent
1	16
2	26
3	24
4	48
5	14
6	20

These moisture contents are generally obtained by the oven method in the usual way, from end sections cut from the sample boards, where the moisture content of the end sections is assumed to apply to the boards themselves. And from such a moisture-content estimate, oven-dry weights are calculated.

At this point the kiln operator asks himself this vital question: How "representative" is the moisture content of these six sample boards? In particular, how "representative" is the 48 percent moisture content of board number 4? Is this high-moisture-content board a "wild" board that might be ignored in selection of kiln settings, or does it mean that an appreciable percent of the kiln charge is in the high-moisture-content range above fiber saturation where too severe an initial setting will result in damage and loss in down grading?

Many persons might approach this problem from a common-sense viewpoint, and point out that since 1 out of 6, or about 17 percent of the readings appear to be above fiber saturation, about 17 percent of the lumber making up the kiln charge is above the fiber saturation point.

Such an assumption is an example of a very common error that is made when general conclusions are drawn from limited data.

It is possible of course that this 17 percent estimate might be correct, in which case an economically correct decision can be made as to the best schedule to use to dry the lumber in the quickest time without costly loss in damage. Many kiln operators, by long experience, and with the knowledge of the source of supply of their lumber and how past kiln charges turned out, and so forth, do a good job in drawing general conclusions from such limited data. It is not the purpose of this article to suggest that these procedures herein described should replace any procedures which through experience have proved satisfactory. It is suggested, however, that any kiln operator, whether experienced or not, might do a better job with the help of some of these elementary statistical procedures.

Now, back to the problem of what to do about the high-moisture-content sample board. Although, as was stated, it is possible that the proportion of sample boards in the small sample of 6 above 30 percent moisture content exactly reflects the proportion of lumber going into the kiln charge that is above 30 percent, the chance that this is not actually true is greater than the chance that it is true. In fact, it can be proved by the theory of statistical probability that, due to laws of chance, even if the kiln charge did have 17 percent of the lumber above 30 percent moisture content, a sample as small as 6 boards would—about 33 percent of the time—present the erroneous picture of none of the lumber going above 30 percent, since 33 percent of the time none of the 6 sample boards would be above 30 percent in moisture content. And conversely, about 27 percent of the time, a sample as small as 6 boards would present an erroneous picture of more than 17 percent of the lumber being above 30 percent, since about 27 percent of the time more than 1 sample board in 6 would be above 30 percent moisture content. In fact, only about 40 percent of the time would the sample exactly reflect the true percent of boards above 30 percent, because only 40 percent of the time would exactly 1 of the 6 boards show a moisture content above 30 percent.

Table 2.—MOISTURE METER READINGS TAKEN ON LUMBER BEFORE KILN DRYING

Percent moisture content—upper class limit	Cumulative number of readings[1]	Cumulative percent of total readings
Less than		
13.5	5	4.3
15.5	20	17.5
17.5	28	24.4
19.5	43	37.5
21.5	58	50.5
23.5	72	62.8
25.5	90	78.5
27.5	97	84.5

[1]Cumulated from an initial sample of 115 readings.

To avoid the pitfall of drawing erroneous conclusions from limited data, two things can be done. A large sample can be taken, or the data that are available can be analyzed in such a way as to yield additional information. But additional sample board moisture measurements taken by the oven method are tedious and time consuming. If more measurements were taken with a moisture meter, those taken on lumber above the fiber saturation moisture content would be unreliable.

These disadvantages were overcome by use of frequency distribution theory. The use of this theory afforded a two-fold method of attack on the problem, in that a larger sample was obtained with meter readings that were rapid and easy to take, and the frequency distribution theory afforded a way to overcome the disadvantage of moisture meter unreliability above the fiber saturation moisture content. At the same time, it analyzed the data in such a way as to increase the amount of useful information that could be obtained.

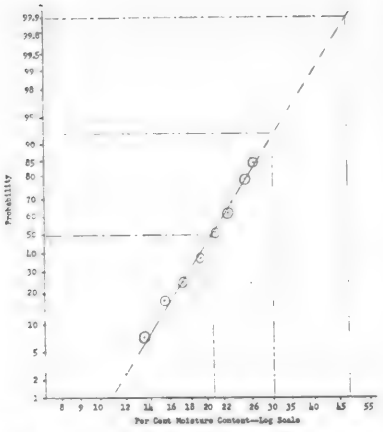

Fig. 4.—Moisture content plot on log-normal probability paper.

Table 2 shows moisture meter data that were typical of readings that would be obtained on air-dried flooring lumber, taken as the lumber was stacked. From such a group of readings the six sample boards previously mentioned might have been selected.

The actual meter reading was not given when the meter read over 25 percent, because it was assumed that the board was above fiber saturation. But even though the actual reading was not recorded, the fact was recorded that a reading above fiber saturation was obtained.

Fig. 4 shows these data plotted as a straight line on log-normal probability paper. The moisture content range above fiber saturation in which individual meter readings were unreliable can be evaluated with confidence by the simple procedure of extrapolating the straight line in Fig. 4. (The dotted portion of the line shows results of this extrapolation.)

It is believed that if the moisture meter is properly calibrated to read moisture contents up to fiber saturation correctly, this procedure will provide a surprisingly accurate picture of the true moisture variation pattern of the lumber, as compared to what would be obtained if the oven method had been used. This will be true, except in unusual cases (such as mixing green lumber straight from the sawmill with air-dried lumber) in spite of the relatively large error associated with individual moisture meter readings[2] and in spite of the fact that individual meter readings are unreliable above fiber saturation.

After the straight line was obtained by extrapolation in Fig. 4, it was an easy matter to evaluate the total moisture variation pattern. From Fig. 4 it was seen that 95 percent of the lumber was included between 36 percent and 12 percent moisture content. The average moisture content was about 21 percent, and about 7 percent of the lumber was above fiber saturation (30 percent moisture content).

With the use of Fig. 4, the wild board question was answered. Fig. 4 indicated that the high-moisture-content sample board was indeed a wild board, since less than one tenth of one percent of the lumber could be expected to be as high as the 48 percent moisture content of this sample board. Fig. 4 also indicated that about 7 percent of the lumber going into the kiln charge was drier than the 14 percent moisture content reading on the driest sample board.

Fig. 4 therefore afforded a clear and meaningful picture of the total moisture variation going into the kiln; and even more important, the relation of the moisture content of the sample boards to the total moisture variation. The kiln operator was able to make a much more informed guess as to the optimum initial kiln schedule to select than perhaps would have been possible if a record had been kept of only the moisture meter readings below 30 percent—or if the distribution of the moisture content of the lumber entering the kiln had been judged only from the oven checks on the six sample boards. Of course, the greater the number of meter readings taken to construct the straight line of Fig. 4, the better it would represent the actual moisture content distribution of the lumber making up the kiln charge. Satisfactory results can be obtained, however, with a sample as small as 50 readings if they are taken at random.

Application of Frequency Distribution Analysis to Moisture Variation Problems of Lumber During Kiln Drying

In Fig. 5 is reproduced the same straight line of Fig. 4, which described the moisture variation pattern of the lumber going into the kiln charge. On the straight line of Fig. 5 was plotted the moisture contents of the six sample boards selected.

Now suppose an initial wet and dry bulb setting has been chosen based on the information provided by Fig. 4, and the kiln charge started through its drying cycle. At the end of a 24-hour period, at the initial setting, the sample boards then weighed might show the moisture contents indicated in Table 3.

The column headed "Current M. C. After 24 Hours" was obtained by cutting intermediate test sections to get a more accurate moisture content estimate of the sample boards. A new oven-dry weight estimate was also obtained from the recut sections, and the original green moisture content of the sample boards was corrected to obtain a more accurate estimate of true sampe board green moisture content. These refinements are probably sometimes ignored in practice, but will considerably improve accuracy of sample board moisture content calculations. In Fig. 5 the effect of these refinements was to decrease the scatter of plotted points about the straight line that estimated the condition of the lumber at any time during kiln drying.

In plotting such a straight line after 24 hours of kiln drying, the following procedure was used: First sample boards on the original line A were re-

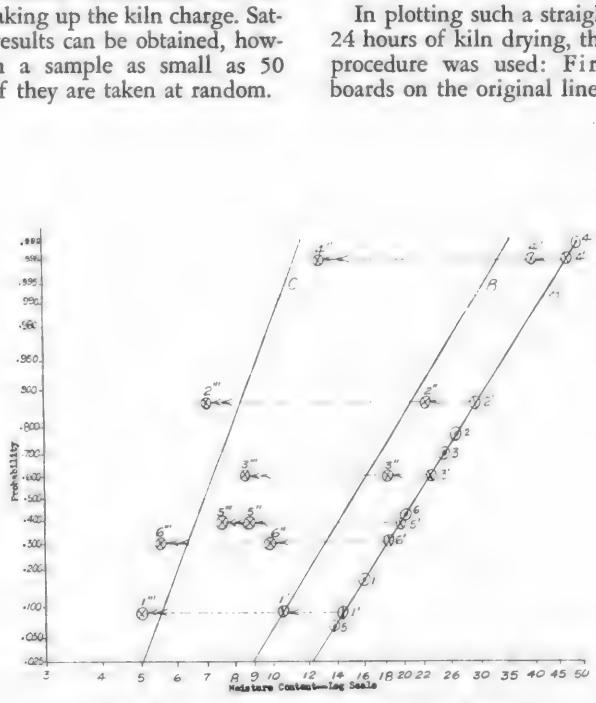

Fig. 5.—Moisture variation during kiln drying.

[2] It is the author's experience that the normal error associated with moisture meters, even when they are functioning properly, is considerably greater than the range of error claimed by most manufacturers of these meters.

located according to their corrected green moisture content. This moved sample board one, for example, from its original position at 16.0 percent to 14.7 percent on the straight line. The other sample boards were similarly relocated, and are shown in their new position by circled x's.

The second step was to plot the sample boards in Fig. 5 at their moisture content values after a 24 hour drying period at the initial kiln setting. For example, sample board one was therefore plotted by projecting the sample board horizontally from its 14.7 percent position to a point vertically over the 10.5 percent moisture content value on the logarithm moisture content scale at the base of Fig. 5.

The other sample boards similarly plotted in their new position after 24 hours are shown on Fig. 5. Now to estimate the moisture condition of the entire kiln charge after 24 hours, a straight line was drawn through all the sample board plotted position. This was line B on Fig. 5.

Line B afforded an estimate of the moisture variation after 24 hours drying of the entire charge. For example, line B showed that the average moisture content was about 13 percent; about 95 percent of the lumber was between 7 percent and 25 percent moisture content, and less than one half of one percent of the lumber was likely to be above the fiber saturation point of 30 percent moisture content. This was true even though one of the six (or 17 percent) of the sample boards were above fiber saturation. Under these conditions, the kiln operator could safely increase the severity of the kiln schedule to achieve a more rapid drying rate with risk of damage to only a negligibly small percentage of the lumber. Without the benefit of this cumulative frequency plot technique, the data from the six sample boards taken by themselves might or might not accurately indicate this condition with resultant loss in kiln drying economies.

By means of the same procedure, the state of the moisture variation in the kiln charge at any time can be evaluated. Suppose that when the time came to consider pulling the kiln charge, the sample boards showed the following moisture contents:

Sample board	Percent moisture content after eight days kiln drying
1	5.0
2	5.0
3	8.5
4	13.0
5	7.5
6	5.5

Line C in Fig. 5 is the straight line drawn through these plotted sample board positions. From Line C the average moisture was estimated at about 7.0 percent, with about 95 percent of the lumber between 5 and 9.5 percent moisture content. Should the kiln operator be satisfied with this degree of uniformity in relation to mill requirements, he could pull the kiln; if not he could leave the lumber in longer, and perhaps change the setting to achieve greater uniformity.

When the lumber is run into the mill, additional moisture reading by oven or meter could be obtained if desired, and plotted in cumulative form on Fig. 5 to see how good Line C was in predicting the actual moisture content of the kiln charge. Another purpose in doing this would be to determine whether sample boards were consistently slower drying or faster drying than the remainder of the lumber. If so, the cause should be determined and eliminated.

Although the preceding use of the cumulative frequency plot during kiln drying is applied to partially air-dried lumber, the same procedure could be followed on green lumber. Here, of course, meter readings could not be used to establish the initial straight line describing the moisture variation pattern of green lumber. But the line could be plotted by taking 40 or 50 oven checks on an initial kiln charge of green lumber.

This same line could be used over and over again on other kiln charges without having to take 40 or 50 new oven checks on each successive kiln charge. This is because the moisture content variation pattern of green lumber would constitute a grand lot that would not likely change (unless it were allowed to air dry partially between sawing and kiln drying) from kiln charge to kiln charge. Simple, yet powerful, statistical methods are available to keep a continuous check whether changes occur in an assumed grand lot.[3]

Application of Frequency Distribution Analysis to Moisture Variation Problems of Lumber Going Into the Mill

For this aspect of the total moisture variation problem, the primary emphasis was one of protecting the mill from running improperly dried lumber into finished products, and a secondary but nonetheless important objective was to provide additional information for analysis and feed-back to the kiln operator for purposes of process control. Several statistical procedures are available, both in the areas of acceptance sampling and in process control, to accomplish these results most efficiently. Only the cumulative frequency technique will be discussed here.

Moisture meters are generally preferred to the oven method in evaluating moisture content of lumber going into the mill because they can be rapidly used. In kiln dried lumber, the moisture-meter accuracy limitation occurs in resistance-type meters in the low moisture content range, since at around 5 or 6 percent moisture content, the electrical resistance of wood becomes so high that it is difficult to measure.

This, of course, is the exact opposite to the moisture-meter accuracy limitation previously discussed when the meter was used on lumber that contained moisture contents above the fiber saturation point. Moisture meters of the capacitance type contain a scale that goes to zero percent, but it is questionable whether accuracy claimed by meter manufacturers for normal moisture range also applies in the low ranges of, say, 3 or 4 percent. Resistance-type moisture meters have no scale reading below 5 percent. Yet lumber that is

[3] Simon, L. E. An Engineer's Manual of Statistical Methods (New York: John Wiley and Sons, Inc., 1941), P. 27.

Table 3.—MOISTURE CONTENT OF SAMPLE BOARDS BEFORE AND DURING KILN DRYING

Sample board number	Original moisture content Percent	Current moisture content after 24 hours kiln drying Percent	Corrected original moisture content Percent
	16.0	10.5	14.7
	26.0	22.6	28.8
	24.0	18.3	23.1
	48.0	35.3	46.5
	14.0	9.0	19.0
	20.0	9.9	18.3

Table 4.—MOISTURE METER READINGS TAKEN ON LUMBER AFTER KILN DRYING

Percent moisture content—Upper class limit	Cumulative number of readings[1]	Cumulative percent of total readings
Less than 11.5	49	98.0
10.5	48	96.0
9.5	46	92.0
8.5	45	90.0
7.5	42	84.0
6.5	36	72.0

[1] Cumulated from an initial sample of 50 readings.

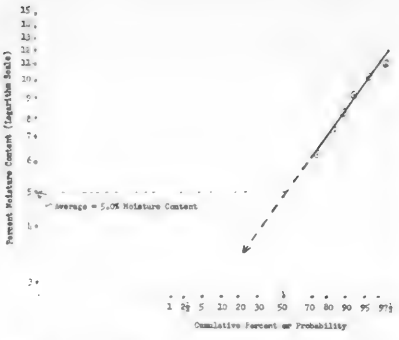

Fig. 6.—Cumulative moisture content plot.

too dry can also give trouble when manufactured into finished products, just as will lumber that is too high in moisture content. The industry speaks wistfully of kiln-dried lumber at 6 to 8 percent moisture content, but it is doubtful if there are many producers able or willing to leave flooring lumber in a kiln long enough to reach this tolerance.

If moisture meters also have limited accuracy in the low moisture content range, how is one going to tell when he has an unacceptable amount of lumber below, say, 5 percent moisture content, on the basis of meter readings? The cumulative frequency distribution can be used to compensate for meter inaccuracy in the low moisture content range, just as it can in the high moisture range. Table 4 shows some meter readings typical of those that might be taken with a resistance-type meter on oak lumber being made into flooring. These moisture readings, which are toward the dry side of the 6 to 8 percent tolerance, might be typical of those obtained on a kiln charge that was either left in the kiln too long, or on which a severe schedule was used where the higher equilibrium moisture content setting at the end of the schedule was omitted in the interest of economy. For the data in Table 4, readings were not attempted below 6 percent, so the lowest moisture content category is listed as less than 6.5 percent.

To study the moisture content distribution in the low moisture region, the data from Table 4 were plotted in Fig. 6 in accordance with the steps previously described for plotting the straight line on log-normal probability paper. The straight line was drawn free-hand through the plotted points. The extrapolated region of the line, represented by its dotted portion, completed the picture of the total moisture variation pattern, which covered the low moisture content region where the meter could not reliably be read on individual boards.

What This Research Means

One important question in kiln drying lumber is how to obtain maximum information about patterns of moisture variation that exist before, during, and after kiln drying at minimum cost. Because of certain factors that limit the accumulation and interpretation of moisture content data, kiln operators in the past have been forced to draw general conclusions from limited data on moisture content. Moisture measurement by the oven method is accurate but time-consuming. Measurement by a moisture meter is rapid but practical and reliable over only a limited range.

A statistical method based on logarithmic normal probability paper has been developed here which overcomes some of these limitations. Its use by a kiln operator should add a new dimension to existing kiln-drying theory and make a significant contribution toward an optimum solution of the problem of moisture control in lumber kiln drying.

From Fig. 6 the average moisture content was estimated as about 5.0 percent, with about 30 percent of the lumber as low as 4 percent moisture content. As in the case of cumulative frequency prediction in the range above the fiber saturation, an experiment can verify the ability of this technique to predict true moisture variation patterns in the low moisture range accurately. Such an experiment could be carried out by taking actual oven readings on the same kiln-dried lumber on which meter readings were obtained. It is the author's opinion that if a properly calibrated moisture meter is used, the cumulative frequency straight line plot will compare favorably with oven test results on the same lumber.

Some factors that will affect the accuracy of this cumulative frequency technique are as follows.

1. **Moisture Meter May Not Be Properly Calibrated:** The effect of this error would be to locate the straight line in Fig. 6, or lines A, B, and C in Fig. 5, somewhat off their true position. Although the cumulative frequency technique is designed to improve the utilization of moisture meter data, the meter itself must be properly calibrated to read correctly average moisture content over a wide moisture range up to fiber saturation point. Some moisture meter manufacturers, particularly of resistance-type meters, furnish detailed instruction as to methods of obtaining more accurate readings on lumber that may not have a uniform moisture gradient, which is lacking in many boards of high moisture content. Such instruction should be observed to get the best performance out of the cumulative frequency technique.

2. **Errors in Estimation of Oven Dry Weight of Sample Boards by the Conventional End Section Technique:** This has already been mentioned; use of intermediate test sections will reduce this error and improve cumulative frequency accuracy.

3. **Failure to Place Sample Boards Properly in the Kiln to Measure the Effect of Any Fast or Slow Drying Areas Which Might Be Present:** Dry kilns with truly uniform drying conditions in all parts of the kiln are probably more the exception than the rule. If this condition is not adequately dealt with by proper location of the sample boards, the accuracy of the cumulative frequency technique will be reduced through no fault of its own.

4. **End Coating Technique:** Poor end coating technique is another possible source of inaccuracy in that sample boards would thereby be allowed to dry faster than the boards in the kiln charge. Proper end coating, properly applied, will therefore also increase the accuracy of the cumulative frequency method.

5. **Number of Sample Boards Used:** The greater the number of sample boards, the better the straight line that can be drawn through the plotted points. Six sample boards were used in the illustration. This is perhaps the minimum number for good kiln drying practice. More than six would be desirable, and would further improve the accuracy of the technique.

6. **Method Used to Draw the Straight Line Through the Plotted Points:** The method used to draw the line in the illustration was the simple free-hand method. More refined methods are available, such as the method of least squares, but the additional calculations required are such that this procedure is not recommended for the average kiln operator. A more productive use of the operator's time in this connection would be to obtain a greater number of sample boards than he perhaps would otherwise.

People, Trees and Direction[1]

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Once the public was alarmed at cutting policies of the logger. Now, public demands have created serious problems for the forest industries. Added, to the traditional ravages by fire, insects, disease, and animals are more recent social, technical and economic threats. To combat them, forestry must go on the offensive.

A SCARCITY OF BIG TREES AND FORESTS? The question never occurred to Alexander MacKenzie who explored parts of the Oregon territory back in 1793. As for John McLoughlin, who governed Hudson Bay Company's operation in the 1830's and '40's and who became affectionately known as the "Father of Oregon," and the thousands of settlers who teamed into the territory via Oregon Trail—the thought of a timber famine just never entered their minds.

Early settlers in the western part of the territory had to burn the forests in order to make room for homes and to make farming and grazing possible. Then, even as now, the forests were managed to meet the people's real, not fancied needs.

However, needs change. As America's population scale tipped westward, growing hordes of people pressed their demands from the forests for shelter, for space to grow crops, plant towns, build railroads, highways, and military reservations. By 1910, the country's popualtion increased from 30 million to 90 million.

Concern for Conserving

By 1910, lumber production in the United States had already surpassed 40 billion board feet for several years. As people took from the forests more rapidly than the forests themselves could replenish, the concern for conserving was born.

Once again, certain needs of the people indicated—really dictated—certain specific forest management practices, and they were put into effect. Forestry schools rose, the first at Biltmore, North Carolina in 1898, at Yale in 1900, at the University of Washington in 1907, and at Oregon State College in 1913. Many more followed. The Bureau of Forestry was energized in 1898 and became the United States Forest Service in 1905. State and private forestry agencies sprang up largely to protect the forests, with their obviously increasing values and uses, from fire.

Population Increase

People have heeded the cry to spare the trees from fire but because of the popualtion explosion they could not heed the cry to spare them from the woodsman's axe and saw.

No slowing of the population increase is in sight. Increasing at the rate of about 3 million per year, U. S. Census Bureau projections based on the current trends indicate that our country will have at least 220 million people by 1975. Furthermore, according to the same report, our population may double again in the second half of the century as it did in the first.

Compounding the obvious demands created by more people has been the doubling and redoubling of living standards, resulting in further demands being created for wood in many uses. One measure of the impact on wood made by these increases of people and their living standards is the estimate that annual American lumber consumption is likely to increase from 36 billion board feet in 1958 to 45 billion, and wood pulp consumption from 23 million tons to about 45 million within the next 15 to 20 years.

Forest Management

Where will all this direct forest management? What will be the problems to confront our forest owners and managers?

The early pioneers were largely concerned with removal—making lumber for homes, making way for fields and pastures. Early foresters were largely concerned with defense—defending the forests from fire, from bugs, from disease and, more recently, from animals.

Fire now has been reduced from an annual major destroyer to a calculable risk through protection efforts producing more efficient techniques, equipment, new fire fighting chemical compounds and through prevention efforts producing better public habits.

Insect and Disease Damage

Lately, foresters have seen a greater need to combat the damage from insects. The need to reduce insect infestation in Washington and Oregon alone still exists on something over 2 million acres and has led to the development of control methods such as new insecticides, aerial spraying techniques, access roads, and sanitation logging in susceptible stands.

As with insects, forests in recent years have become increasingly aware of and knowledgeable on disease problems. Less spectacular than fire and insects, disease damage has been more difficult to assess and control. But through teamwork research, the cooperative efforts of private, state and federal forest managers have begun to attack disease with accelerated vigor and effectiveness.

Damage by Animals

Damage to western forests by animals at times has been startling. Time after time, forestry efforts have been sacrificed to all kinds of rodents—from seed eaters to bud nibblers, from cone stealers to dam builders and from limb and root pruners to bark biters. To deer and elk to the hyperactive black bear and rodents, our company attributes annual damages of a million dollars to young growing stock on our tree farms.

Problems of fire, insects, disease and animals will not be erased from future forestry plans. Foresters will learn to

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[1] Presented at the Wood Industries Conference, September 10, 1959, in Portland, Oregon. Approved for publication July 1960.

live with them. The risks they bring to management certainly must and will be further minimized.

The People Problem

What of the problems, however, caused by shear masses of additional people? Where once the public was alarmed at the speed by which the logger was removing the forests, it is now the logger and forester who view with alarm the speed by which the public is taking forestland out of commercial forest production. Driven by needs for powerline rights-of-way, roads, dams, airfields and related facilities, public and other agencies, from 1945 through 1953, reduced commercial forestland in western Oregon and Washington an average of 70,000 acres each year. This average annual acreage loss is equivalent to about one-third of the total timber area annually harvested in the Douglas-fir region of the two states. Reflecting this trend, the Forest Service has estimated that where there are three acres of commercial forest growing lands for each American today, there will be only about one and three-fourths acres within about 40 years.

Related Threats

The Secretary of the Interior points to a related threat. Nearly one and one-fourth million acres of good farm land are lost each year to housing, airports, factories, highways, and shopping centers. By 1975, more than 20 million acres of today's farmland will be used for these and other nonfarming purposes. At the same time, our population will have increased, he contends, by nearly 60 million.

From the uplands comes another concern. Historically, conversion of the wilderness to a productive, beneficial land, has been synonomous with building the nation. It certainly is appropriate to preserve some typical areas of wilderness to round out some of our specialized recreational needs. Many foresters, however, view with alarm the desires of some recreationists to reduce vast productive areas into wilderness preserves. Commercial forests are being squeezed by booming populations in the lowlands, by wilderness developments in the highlands and by powerlines, pipelines, freeways, dams and parks in between. All of these, of course, are necessities in themselves. It is clear that one of the forester's problems will be to grow more and more wood on less and less land.

Not only will more wood have to be grown on fewer acres, but forestlands that will remain for the primary purpose of growing wood commercially will be increasingly shared by growing numbers of hunters, fishermen, picnickers, campers and other users with their legitimate recreational needs.

Offensive Attack

Forestry, which has been largely on the defensive for the past 50 years must go on the offensive. The forester has learned that he must enlist numerous allies to aid in solving management problems. Increasingly, he must rely on team effort by natural and physical scientists to solve increasingly complex problems. Maximum wood production resulting from more intensive forestland management can only be achieved within practical costs by minimizing present losses from the destructive and growth-hampering agencies of disease, insects, animals and others.

Attack on Diseases

Diseases, the greatest threat to forest productivity, are estimated roughly to be responsible for nearly 20 billion board feet lost annually from growth in American forests. Requiring increased attention by pathologists, photogrammetrists, soils specialists, silviculturists, geneticists and chemists, diseases must be treated with chemical therapy, improved silvicides and fungicides, and systemics and other chemicals. Susceptibility of trees to disease attack is often closely related to biological and chemical factors in the soil. Fertilizers have given promising results in reducing disease damage, as well as stimulating growth and cone production on coniferous trees.

Attack on Time

Chemists will play an ever-increasing role in reducing the time it takes to complete a forest growing cycle. Selective herbicides that help control brush and weed competition and new reforestation techniques already are making it possible to reduce a 90-year growing cycle from 5 to 10 percent by allowing immediate establishment of a new crop. Rodent repellents, applied directly to the seed, have made aerial seeding practical by reducing the threat of the little animals which eat seeded areas clean. If chemical growth stimulants prove as effective as some scientists hope, we may sometime be able to grow two crops during the period it now takes to grow one.

More work will have to be done on research that has already begun on increasing the regularity of cone crops, increasing the quantity and quality of seed, and the selection of fast-growing superior strains that are insect and disease resistant. In the process of replacing the wild trees grown in nature without man's help, we have an opportunity to replace them with hybrid, tame trees superior to those grown unassisted by nature.

Pacific Northwest Costs

Any strengthening of forest product demand will almost automatically speed up the advance of intensified forestry. But the Pacific Northwest forest industry must aggressively seek solutions to its problems because they represent serious obstacles to successful competition with the industry in other parts of the nation and the world—and to successful competition with non-wood materials. Costs are higher in that area than in other producing areas. Freight costs often represent one-third or more of the selling price. Local and state taxes in the Pacific Northwest conservatively are 50 percent greater than in much of the South. Wage rates in the Pacific Northwest are in a 2 to 1 ratio with wages in the industry in the South.

The opportunity for improving begins in the woods with less breakage in the falling of timber; with more efficient and cheaper yarding, loading and transportation methods and equipment; by finding ways to increase economically the utilization of present woods residuals, as well as softwood thinnings and hardwoods. It applies in the sawmills where wood sawn evenly reduces shavings waste, in plywood mills where a rotary lathe that cuts smoothly produces higher quality veneer, in plants where particleboard "on size" eliminates the waste of sanding.

Uses for Raw Materials

We can do more with what we have today through finding new uses for raw material presently begin consumed at a no- or low-realization point, such as breaking through the mystery of the composition of lignin, the second largest constituent of wood. This unsolved mystery limits the utilization of up to half of the pulp log and pulp chips to a few applications. More than 500,000 tons of lignin are estimated to be available in the Pacific Northwest each year. Only a few products and uses have been unfolded from the complex matter. These have limited demand or relatively low worth today.

Related to this is the need to develop more commercially profitable product from bark which represents 10 percent of the tree substance. Both it and lignin, according to some researchers, hold the possibility of providing key chemicals. Our own project scientists and others are hopeful that the organic raw materials of the forest may ultimately become the basis of a chemical industry in much the same way as oil or petroleum has become the basis for the petrochemicals industry.

Taxation Threat

Many, but not all, of the future problems facing forest land owners and managers will be technical problems, or economic problems related to technical ones. One of the greatest potential problems is the constant threat of unreasonably imposed taxation. This cloud hovers over all privately owned forests. It is constantly in the minds of those who must decide whether or not it is feasible to invest money today in a crop that may not be harvested in their own lifetime, whether at a profit or not. Taxation—like fire—can be an unreconcilable hazard or it can be a calculable, reasonable risk. Those concerned with forest management must contribute substantially to development of a long range public policy and to laws that keep taxation on forest investments on a basis that is equitable with taxation on other investments.

Social Problems

Forest managers must also work out broader uses of their lands for recreation, for developing and storing water and for other important, non tree-growing uses. As a corollary to this, the public must increasingly accept the multiple-use principle on public lands in order that these lands contribute to the assurance that there will be sufficient wood growing lands to meet anticipated demands. Realistic land-use policies that will protect both long established property rights and long range public interests must be developed and must be constantly re-evaluated.

It was William Blake who observed that what is now proved was once only imagined. Certainly Alexander MacKenzie, John McLoughlin and other early pioneers in this part of the country never imagined the problems in forest management that we and our predecessors have already met and solved.

The seventh and final report of a series of studies to establish sound principles of moisture movement in wood.

DETERMINING THE DISTRIBUTION OF

Interstructural Openings in Wood[1]

A METHOD IS DESCRIBED for determining the distribution, according to size, of the interstructural openings (pit membrane pores in both softwoods and hardwoods and tyloses pores in hardwoods); that control the rate of passage of liquids and vapors through wood. The method involves measuring the pressure required to cause increasing amounts of octyl alcohol to pass through water-saturated wood. The pressure required to force the interface between water and octyl alcohol through a capillary deepnds upon the effective radius of the capillary and the interfacial surface tension between the two immiscible liquids. Data and calculations are given for spruce heartwood cross sections of several different thicknesses. The most effective radius for the specimens tested ranges from 135 to 450 millimicrons, and the most probable effective radius for flow ranges from 30 to 80 millimicrons as specimen thickness decreases from 1.5 to 0.5 inches.

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Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Wood is a highly porous material. When dry, it varies in void volume from about 45 percent at a specific gravity of 0.80 to 85 percent at a specific gravity of 0.22. It is not, however, a very permeable material, because the intercommunication between fiber cavities in all woods occurs only through openings in the pit membranes that are usually submicroscopic in size. Although the pores or vessels of hardwood are relatively continuous tubes, passage through them is frequently restricted by tyloses containing submicroscopic openings. These two types of fine openings control the ease of penetration of wood with preservatives, fire retardants, and dimension-stabilizing and pulping chemicals. They are also effective in modifying the mechanism of the movement of water through wood during drying (13).[3]

A limited amount of information regarding pit permeability has been obtained for softwoods by several methods. The fractional effective cross sectional area of the communication capillary structure was determined from the rate of electro-osmotic flow of water through wood (9, 10). The average radius of a pit membrance pore has been estimated from a combination of the rate of flow of water through wood under pressure and the rate of electro-osmotic flow (9, 10). The distribution of pit membrane pore sizes has been estimated from the rate of flow of air through wood under pressure at different relative humidities (11). The most effective size of the openings has been estimated for wood and other membrance from the pressure required to cause the first air bubble (air-water meniscus) to pass through the water-saturated material (1–3, 8–10).

Average effective pit membrane pore radii of about 16 millimicrons were obtained by combining pressure permeability and electro-osmotic flow data for Alaska-cedar and western redcedar heartwood (9). An average effective pore radius of 28 millimicrons was obtained from data for the flow

The Author: Dr. Stamm, formerly a subject matter specialist at the USFPL, holds a Ph.D. from the University of Wisconsin. He is now on the faculty of North Carolina State College. Eugene Wagner was a student assistant at the laboratory at the time this study was undertaken.

[1] The seventh of a series of contributed articles received August 20, 1959; approved for publication March 18, 1960.

[2] Maintained at Madison, Wisconsin., in cooperation with the University of Wisconsin.

[3] Numbers in parentheses refer to Literature Cited at the end of this article.

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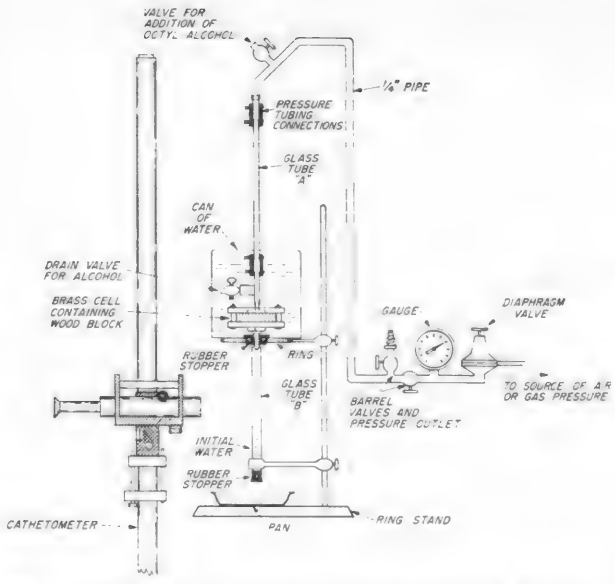

Fig. 1.—Diagram of experimental equipment developed to measure pressure required to move liquid through water-saturated wood.

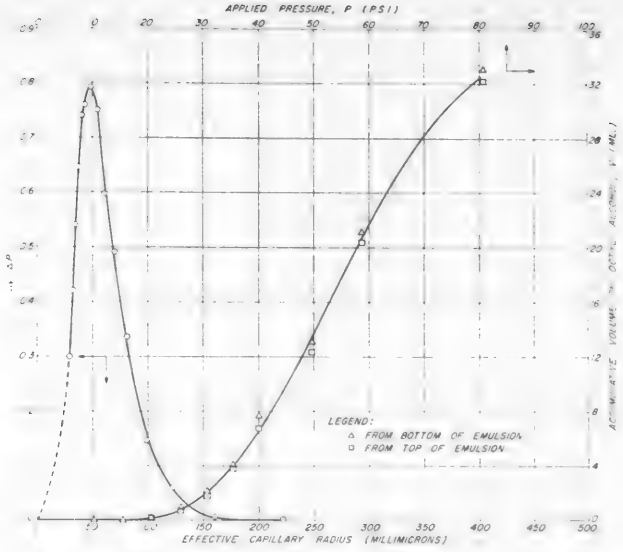

Fig. 2.—Relationship between the volume of octyl alcohol passing through a 1-inch-thick section of Sitka spruce heartwood and the pressure, when held for 5-minute intervals, and the relationship between the rate of volume changes in pressure and the effective radius for the same specimen.

of humidified air through the heartwood of western white pine (11). The heartwood of several softwood species gave most effective capillary radii of 40 to 110 millimicrons from data for overcoming the surface tension of water (12). Sapwood values ranged from 420 millimicons for Douglas-fir to as high as 11,000 millimicrons for slash pine (12). The latter-high value is possible only if a spanning membrane is absent in part of the pits, or if the passage of air is through only partially obstructed resin ducts.

The only one of the foregoing methods that is sufficiently simple for routine measurements is the method for overcoming surface tension. This method gives only maximum sizes. The results furthermore, are quite dependent upon the rate at which pressure is applied. A new simple method for measuring the radii of the effective communicating capillary structure of wood is hence needed in order to gain a better understanding of wood permeability.

The method developed by Bechhold (4, 5) for determining the distribution of pore sizes in synthetic membranes seemed promising for this purpose. It involves the combining of measurements of force necessary to overcome the resistance of the structure to passage of menisci with the rates of capillary flow. When the pressure is increased beyond that required to displace the liquid from the most effective capillary by overcoming the effect of surface tension in its smallest cross section, flow of air (4) or a displacing liquid (5) occurs through this capillary at a rate that increases proportionately with an increase in applied pressure. Liquid is at the same time displaced from capillaries with somewhat smaller effective radii. The flow through the membrane will thus increase at a faster rate than that which is directly proportional to the pressure.

What this Research Means

Impregnation of wood with preservatives, fire retardants, and dimension-stabilizing and pulping chemicals, as well as the drying of wood, all involve the passage of material through fine interstructural openings. Those largely determine the rates of impregnation and the pressures required. It is hence of vital importance to understand the mechanism of this passage and to collect statistical data for the effective sizes of these fine openings in various woods. This article describes a simple method of measuring the distribution of these pore sizes, together with preliminary data.

The rate of increase of flow with an increase in pressure $\triangle V/\triangle P$, is thus a function of the additional capillary cross section that is becoming effective. When this function, $\triangle V/\triangle P$, is plotted against the effective radii, a distribution curve is obtained that indicates the fractional effective cross-sectional area of capillaries of each size versus the capillary radius.

This report covers the adaptation of Bechhold's method to measurements on wood cross sections.

Preliminary Experiments

Preliminary measurements were made to determine the air pressure required to displace water from water-saturated cross sections of wood. The amount of water displaced from the wood was determined by the weight of water taken up by a bubbler flask containing sulfuric acid. The amount of air passing through the specimen under any definite pressure beyond that required to overcome surface tension in the largest effecting capillary was measured with a flow meter. When the amount of air passing through the specimen because large, it tended to carry sulfuric acid with it. The sulfuric acid bubbler was then replaced with a series of flasks containing phosphorus pentoxide suspended on glass wool.

There proved to be four major objections to this technique for making the necessary measurements, other than using it merely to measure the pressure required to cause the first air bubble to pass through the specimen. These objections were:

(1) Such high pressures (several hundred pounds per square inch) had to be applied to displace a significant part of the free water from the specimens that leakage was hard to prevent around the edges of the specimen and cell. 2) When the rate of air passage through the specimens became appreciable, it caused adjacent fibers to dry before air passed through them. 3) Because of the compressibility of air, volume corrections for the expansion of air as it passes through the specimen would be necessary to obtain

quantitative results. 4) Flow of air through the fine pit membrance pore structure would be affected by the fact that many of the openings are smaller than the mean free path of air molecules under normal atmospheric conditions (13). This effect might persist up to sizable pressures. The rate of flow of air through any one capillary path might not, therefore, be proportional to the pressure. This procedure was hence abandoned in favor of displacing water with another immiscible liquid.

Equipment and Method

The liquid chosen was octyl alcohol. It wets wood readily, has the low interfacial surface tension of 8.4 dynes per centimeter as determined with the duNoüy torsion balance (7), and its vapor pressure is relatively low.

Figure 1 gives a diagrammatic sketch of the equipment used. It consists of a high-pressure source of compressed air, a sensitive diaphragm pressure-reducing valve, a 100-pound-per-square-inch pressure gage readable to 0.5 pound per square inch, and a globe shut-off valve, all connected in series with ¼-inch pipe to a pressure release valve and a vertical pipe which, at a height of 4 feet, turns downward again at an inclined angle of 45 degrees. Another globe valve is connected to the inclined part of the pipe for filling the equipment with octyl alcohol. Just beyond the point where the pipe again becomes vertical, it terminates in a hose nipple.

A thick-walled Pyrex glass tube, *A*, 18 inches long by 12 millimeters in outside diameter, with a predetermined internal volume per unit of length, is attached to the hose nipple with high-pressure rubber tubing. The bottom of the glass tube is attached in like manner to a hose nipple on the top half of the specimen cell, which is provided with a side drain valve. The cell consists of two rectangular brass plates ½ inch thick by 3 inches square. Each of these has a conical recess at its center 1 inch in diameter at the surface and terminating in a ¼-inch diameter hole from mid-thickness to the other surface of the plate. Bolt holes ⅛ inch in diameter are drilled through the plates ½ inch from the corners for use in clamping the wood cross sections between the two half cells, with rubber gaskets separating them.

The cell with a hose nipple on the bottom fits through the bottom of the water-jacket container. Water in the jacket serves to keep the edges of the specimen wet, and also as a detector for leaks in the cell as indicated by the appearance of a film of octyl alcohol on the surface of the water. A calibrated lower glass tube, *B*, having the same dimensions as tube *A* with a stopper in the bottom, is clamped in a vertical position beneath the bottom hose nipple.

The measurements were made on air-dry Sitka spruce heartwood cross sections ranging from 0.5 to 1.5 inches in thickness and 2.25 inches square. They were impregnated with water saturated with octyl alcohol by the vacuum desiccator technique. They were weighed and their tangential and radial dimensions measured to the nearest 0.001 inch just before use.

A wood specimen was clamped in the cell. The cell assembly was fitted through the rubber stopper in the bottom of the water jacket and attached to the pressure line. Just enough water was added to the jacket to cover the cell. Distilled water containing about 1 percent of ferric chloride and saturated with octyl alcohol was poured into the bottom tube (*B*, Fig. 1) to a depth of about an inch. Octyl alcohol saturated with water was added through the top valve to fill tube *A* to about 1 inch from the top. The height of octyl alcohol in tube *A* and that of water in tube *B* were read with a cathetometer to the nearest 0.01 centimeter.

After closing the valve between the equipment and the source of air pressure, as well as the pressure release valve and the valves for filling the equipment with octyl alcohol and for draining it, the pressure was built up to about 5 pounds per square inch by opening the valve to the source of air pressure slightly. The valve to the equipment was then slowly opened. When the pressure was again built up to its full value of about 5 pounds per square inch, a stop watch was started. The pressure was read at 1-minute intervals for 5 minutes, after which the pressure -release valve was opened and the height of the liquids in the two glass tubes read with the cathetometer. The pressure-release valve was again closed, the pressure raised a few pounds per square inch for a 5-minute period, and the cathetometer measurements repeated after opening the pressure-release valve.

The pressure was noted under which the first milky appearing drop of liquid (octyl alcohol emulsified in water) was forced from the specimen. This occurred at anywhere between 5 and 20 pounds per square inch, depending on the thickness of the specimen. The pressure was raised by 5 to 10 pounds per square inch at a time until a lens of octyl alcohol formed on the surface in the lower tube, *B*, when both the lower and upper liquid-liquid interfaces and the upper surface heights were measured. Octyl alcohol becomes emulsified in water as it is ejected from the specimen. The ferric chloride is added to the water in tube *B* to aid in breaking the emulsion. Even so, there is a tendency for a small amount of emulsion to persist at the interface. For this reason, the heights of both the bottom and the top of the emulsion were determined.

When the level of octyl alcohol in the upper tube, *A*, became low and that in the lower tube, *B*, became quite high, the valve between the equipment and the source of pressure was closed without disturbing the air pressure adjustment. The pressure-release valve was opened to release the pressure in the equipment. Tube *A* was refilled to about an inch of the top with water-saturated octyl alcohol. Tube *B* was then emptied, and octyl-alcohol-saturated water containing ferric chloride was added to a depth of about an inch. The valve for filling the equipment with octyl alcohol and the pressure-release valve were closed, the valve to the source of pressure slowly opened, and the measurements resumed. Measurements were not carried above 88 pounds per square inch because of the tendency for leaks detectible by the drop in octyl alcohol level in the upper tube to exceed the displacement of liquid into the lower tube and the appearance of octyl alcohol on the surface of the water jacket around the cell. Normally, two fillings of tube *A* (which had a capacity of about 30 milliliters) supplied all the liquid needed to carry the measurements to the high pressure of 88 pounds per square inch.

The pressure was released, the cell disassembled, and the specimen weighed and measured. It was then oven-dried, weighed, and again measured.

The minimum suitable time interval for maintaining the pressure was determined by applying pressures of 11 or 21 pounds per square inch to displace water from 0.5-inch thick specimens of Stika spruce with octyl alcohol. The volume of octyl alcohol passing through the specimens was determined at 5-minute intervals over a period of 1 hour. In both cases, the volume passing through was directly proportional to the time over the full range. Proportionality is thus atttained in the first 5 minutes, so this interval was deemed adequate.

Calculations

The effective capillary radius, *r*, corresponding to each average applied pressure was calculated from the equation

$$r = \frac{2\sigma}{P}\cos\,\Theta \qquad (1$$

where σ is the surface tension or interfacial surface tension of the liquid-

air or liquid-liquid system in dynes per centimer, P is the applied pressure per unit area in centimeter-gram-second units and Θ is the angle of wetting (16). Because octyl alcohol wets wood and has a low interfacial surface tension against water, Θ may be considered to be zero and $cos\ \Theta$ equal to 1.00. When r is expressed in millimicrons (10^{-7} centimeters) and P is in pounds per square inch, the equation becomes

$$r = \frac{2435}{P} \qquad (2$$

In Figure 2, the accumulative volume of octyl alcohol in milliltiers passing through a 1-inch-thick specimen of Sitka spruce heartwood is plotted against the applied pressure when each amount of pressure is held for a total time of 5 minutes. The volume of octyl alcohol passing through the wood was calculated from both the lower and the upper meniscus of the interface. The true value should be somewhere between these two measured values. Figure 2 shows that the error introduced by making only one meniscus measurement would be relatively small.

The rate of change of volume with pressure, $\triangle V/\triangle P$, as shown by the slope of the volume-versus-pressure curve, is plotted against the effective

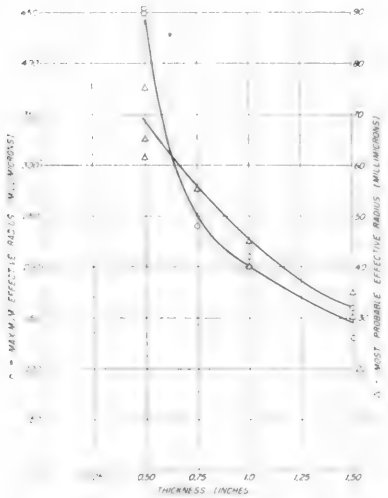

Fig. 3.—Relationships of maximum and most probable effective radius for cross sections of Sitka spruce heartwood to thickness of specimens.

capillary radius in Figure 2. It gives a fairly normal type of distribution curve. The first drop of octyl alcohol passed through the wood at a pressure of 15.5 pounds per square inch. This corresponds to a maximum effective capillary radius of 157 millimicrons. Extrapolation of the plot to $\triangle V/\triangle P = 0$ gives a value of 180 to 200 millimicrons. The maximum of the distribution curve represents the most probable effective radius. In this case it corresponds to an effective radius of 47 millimicrons.

Similar measurements were made on Sitka spruce cross sections ranging from 0.5 to 1.5 inches thick. The maximum effective pore radii and the most probable effective pore radii are plotted against the thickness of the specimen in Figure 3. Both the maximum and the most probable effective radii increase with a decrease in thickness of the specimen, the maximum more rapidly.

Conclusions

The increase in both the maximum and most probable effective radii with a decrease in thickness of the specimens would be expected, because the menisci between octyl alcohol and water will on the average have to pass through only 2.6 pit membranes in series in traversing the 0.5-inch-thick specimens, whereas they will have to pass through about 10 pit membranes in series in passing through a specimen 1.5 inches thick. These pit numbers were obtained on the basis that the average fiber length is 0.35 centimeter and the menisci will travel through an average of half a fiber length at each end without passing through a pit membrane. The more pits that are traversed in series through the most effective path, the greater is the probability that some of the most effective pores in this path will have radii of less than maximum size. The same should be true, but perhaps to a somewhat lesser extent, for the most probable pore sizes, since these are still well above the average size, as will be shown later.

The specimen of Figure 2 had an initial moisture content of 205 percent, or a displaceable free-water content of 175 percent. The loss in weight between the initial and final displaced condition was only 2.15 percent of the block as a whole or 15.0 percent of the unmasked area. Dividing this by the difference between the specific gravity of water and that of octyl alcohol (0.173) gives 86.7 percent of water displaced. This is 49.5 percent of the water that could have been displaced.

Given enough time, some water could be displaced from all of the fiber paths, even at low pressure, up to the point that octyl alcohol reaches the first pit to be traversed. At equilibrium, this could amount to 6.7 percent (half a fiber length divided by the thickness) of the displaceable water. This portion of the displaceable water was exceeded only after holding the pressure at 15.5 pounds per square inch for 5 minutes, when octyl alcohol just began to pass through the wood. Water had hence not been displaced from half of the fiber paths when the measurements were terminated.

The most probable effective pore radii obtained from Figure 2 and similar curves is on a volume flow basis. On a number basis, for pores with a 25-millimicron radius to be as effective on a flow basis as pores with a radius of 50 millimicrons, there would have to be 16 times as many of them, because flow varies as the fourth power of the radius (9, 12). In Figure 2, the flow effectiveness of the pores with a radius of 50 millimicrons is shown to be 2.6 times that of the pores with a radius of 25 millimicrons. There must thus be about 16/2.6, or 6.2 times as many of the smaller pores as of the larger. The fact that a most probable pore radius exists for flow conditions does not imply that there is also a size with a most probable number of pores. If such a size exists, it would have to be well below the range of the size measurements considered here.

Before more exact conclusions can be drawn, it will be necessary to collect a great deal more data and subject it to more extensive mathematical analysis.

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THE RELATIONSHIP BETWEEN

Gamma Ray Absorption and Wood Moisture Content and Density[1]

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THE USE OF RADIATION methods in recent years has become prominent in the measurement of material quality. Thus, it has become of great interest to the wood technologist to determine the feasibility of the use of radiation methods for rapid, accurate, and non-destructive physical measurements of wood properties such as moisture content and density. Of the radiation sources available at present for these radiation methods, the three major ones of interest to wood technologists are X-rays, beta rays, and gamma radiation.

Using the transmission method, Berseniev and Fokina (1)[2] found that the penetration of beta rays into wood is dependent on the gross density and thickness of the specimen: as gross density and thickness increase, penetration decreases. A break point in curves of counting rate versus moisture content (M.C.) was observed between 30 and 40 percent M.C. and was believed to be due to the fiber saturation point (F.S.P.) of the wood. They conclude that beta rays can be used for quick determination of moisture content in wood under laboratory conditions or for automatic measurement of the moisture in veneer, plywood or other thin wood.

Cameron (2) has developed a semi-micro method of density determination. This method is based on a radial strip of wood prepared from an increment core, which is scanned in 0.5 mm. steps by a collimated beam of beta rays from a strontium-90 source. In this manner, the variation in density across individual growth rings of Douglas-fir was observed. Gravimetric density determination on sections comparable to these 0.5 mm. steps were obtained and agreed within 2.5 percent of the beta ray determinations.

Lakatos (3) used a mechanically collimated gamma ray with a Geiger-Müller (G-M) counter, and found that

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If specific gravity or moisture content is known, the other can be determined nondestructively, rapidly, and accurately by measuring gamma ray attenuation through a given thickness.

there is a relationship between the absorption of gamma rays and density at a given moisture content or vice versa. X-ray sources were also used, but were not energetic enough to penetrate the wood at higher moisture contents and densities. Conversely, the gamma rays used were too energetic (hard) to be attenuated sufficiently by the wood to give accurate density readings. In another study, Iizuka (4) obtained good correlation between counting rates measured with a G-M counter and moisture in log cross sections, as long as the section was free of knots and had uniform grain orientation.

Parrish (5) established various gamma radiation—wood moisture and density relationships, which he then used in an attempt to detect decay in standing timber or in logs. In this work he used a scintillation probe in conjunction with a gamma ray spectrometer. He was able to detect interior cavities by measuring variations in the absorption of gamma radiation due to differences in density. This method did not work when the decayed area was filled with water.

The gamma ray transmission method was selected as the one to be investigated to the fullest extent. It is known that there exists a relationship between monoenergetic gamma ray attenuation and density. This study was initiated with the objective of determining whether this relationship is sensitive enough to measure gross density variations encountered in wood. These gross density variations are the result of variations in wood specific gravity and moisture content.

[1] A 1960 Wood Award Entry, based on research done under Project HM-21 of North Carolina Agricultural Expt. station in cooperation with the USDA Forest Service, Southeastern Forest Expt. Station, Asheville, N. C. Revised for publication Jan. 26, 1961.

Materials and Methods

Equipment and Source: A scintillation counting system was used to measure the gamma ray attenuation. This system consisted of a Detectolab model DP4, probe and shield; a Detectolab model DZ45, gamma ray spectrometer; and a Baird-Atomic Glow-Tube Counter, model 131-A. The source used was one millicurie (mc.) of lead-210 (radium D), which has a half-life of 22 years and a primary energy peak of 47 Kev.

Specimen: A 6-centimeter-thick octagonal-shaped specimen was used. Dimensions of the specimen and the axis of radiation passage are shown in Fig. 1. Yellow poplar sapwood *(Liriodendron tulipifera* L.) was used to make the specimens.

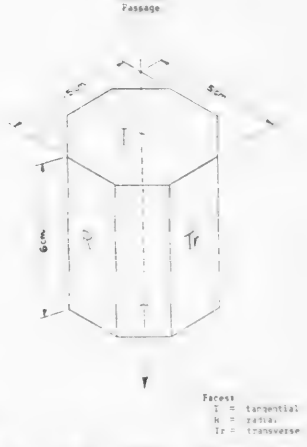

Fig. 1.—The specimen shape, size, and grain orientation, and axis of radiation passage.

Sample Selection: An initial group of about 150 samples, representing several treets, were machined to equal-sized billets and weighed. From this initial group an intermediate group of clear, straight-grained specimens was selected so as to be evenly distributed over the range of weights. It was thus assured that the group would provide a reasonably wide range of specific gravities. The selected billets were then machined to the dimensions and shape shown in Fig. 1. At this point, the

specimens were carefully examined for proper grain orientation and minimum ring curvature. Specimens were saturated with water by means of vacuum-pressure cycles. They were then weighed (Ws) and their volume (Vg) determined by the water displacement method. From these data, an estimate of specific gravity on a green volume, oven-dry weight basis (Sg) was obtained by using the following expression derived from Brown and coworkers (6).

$$\hat{Sg} = 2.887 \left[\frac{Ws}{Vg} - 1 \right] \quad (1)$$

These estimates were used for selecting the 16 samples to be used in this study. Accurate specific gravity values (based on oven-dry weight, green volume) were determined after the oven-dry weights were obtained, upon completion of 0 percent moisture content gamma ray attenuation readings.

Moisture Content Control: The moisture levels selected for this project were saturation, fiber saturation, 18 percent, 9 percent, and 0 percent. Saturation was obtained, as previously mentioned, by a series of vacuum-pressure cycles. An approximate fiber-saturation level was obtined by exposing the specimens to an enclosed atmosphere over water. Since fiber saturation could be obtained only by bringing the specimens up from a lower moisture content, the 18 percent level was evaluated second and the fiber-saturation level third. The 18 and 9 percent moisture content levels were obtained by exposing the specimens to an atmosphere controlled by the proper concentrations of sulfuric acid solution (7). The 0 percent moisture content level was obtained by drying the specimens at 105°–110° C.

The specimens were weighed periodically at each humidity level, and when they reached a constant weight, it was assumed that they were in equilibrium with the controlled atmosphere around them. They were then quickly wrapped in Saran Wrap (vinylidene chloride), and the seams sealed with cellophane tape. Saran Wrap is a thin (0.0005 inch) film material with a low moisture transmission rate (0.01–0.03 g./24 hrs./m²/mm. thickness/cm. Hg @ 25 degrees C.), which makes it quite suitable as a wrapping material for the specimens. A double layer as used on the sample (top and bottom faces) is only 0.04 percent of the total specimen thickness of 6 cm. Therefore, the wrapping material was not considered as a source of error.

Gamma Ray Spectrometer Measurements: When the gamma ray spectrometer was used in conjunction with the scaler, the lead-210 source spectrum was obtained as shown in

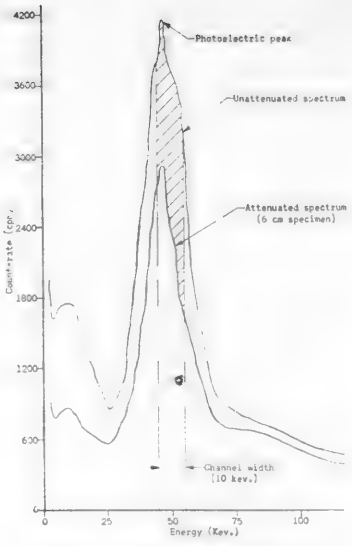

Fig. 2.—Lead-210 spectrum.

Fig. 2. The lower discriminator E of the spectrometer was set on the photoelectric peak and the upper discriminator or window ΔE was set at 2 volts, which is 1 percent of E or 10 Kev. (E equals 1,000 Kev. full scale). The voltage was set at 950 volts. Minor adjustments in the lower discriminator setting had to be made from time to time, due to changes in the electronic characteristics of the equipment used. Throughout this study the unattenuated counting rate in counts per minute (cpm), I_0, was measured for 2 minutes, which gave a value of approximately 100,000 counts. The attenuated counting rate, I, at each of the moisture levels previously mentioned was measured for the appropriate length of time to give a value of approximately 100,000 counts. Counting times for the moisture levels used were as follows:

1) Seven minutes, saturation
2) Four minutes, fiber saturation
3) Three and one-half minutes, 18 percent moisture content
4) Three minutes, both 9 and 0 percent moisture content

At each of these moisture levels, I_0 readings were determined for the system before the specimen was measured. The specimen was then placed in the system and I was obtained. These I_0 and I readings were considered as a pair. A second pair of readings was taken immediately with the specimen inverted. Specimen thickness and weight were also determined. The distance from source to detector was held constant at 10 cm. throughout the study. After about one week, this entire process was repeated to provide a replicate. The specimens were then conditioned to the next moisture level. Since I_0 readings varied somewhat over a period of time, paired readings were taken to minimize this source of error. Inverting the specimen tended to minimize the difference between the total volume measured by the standard method and the conical volume measured by the gamma radiation method.

Data were placed on IBM cards and analyzed on an IBM model 650 digital computer.

Results and Discussion

Data Transformation: It was felt that, by using certain transformations, the date collected could be put into a form which would readily lend itself to analysis. The transformation used was derived from the following exponential equation for radiation attenuation:

$$I = I_o e^{-uxp} \quad (2)$$

I = attenuated counting rate, counts per minute (cpm)
I_o = unattenuated counting rate (cpm)
e = base of the Naperian logarithmic system
p = gross density of the absorbing material (g./cm.³)
x = absorber thickness (cm.)
u = mass attenuation coefficient for a given radiation wave length and absorbing material (cm.²/g.)

Re-arranging Equation 2 and designating $u \times p$ as y, (linear absorption co-

Table 1.—TABULATION OF SPECIFIC GRAVITIES, X_1; AVERAGE LINEAR ABSORPTION COEFFICIENT, Y; AND PERCENT MOISTURE CONTENT, X_2

Specimen	X_1[1]	y	X_2	y	X_2	y	X_2	y	X_2	y	X_2
1	0.310	0.1827	247	0.0773	26.66	0.0740	18.48	0.0676	9.34	0.0665	0
2	.330	.1840	227	.0826	26.64	.0768	18.31	.0751	9.30	.0704	0
3	.345	.1972	224	.0862	28.28	.0811	18.81	.0787	9.38	.0743	0
4	.361	.1983	211	.0891	26.81	.0829	18.45	.0826	9.40	.0764	0
5	.381	.1977	198	.0937	27.56	.0876	18.92	.0846	9.40	.0798	0
6	.384	.1987	195	.0941	28.35	.0886	18.54	.0852	9.37	.0817	0
7	.399	.1991	185	.0955	26.65	.0918	18.50	.0918	9.34	.0838	0
8	.418	.1998	174	.1008	26.23	.0961	18.43	.0927	9.40	.0875	0
9	.482	.2009	142	.1123	25.34	.1083	18.48	.1054	9.44	.1005	0
10	.423	.1983	171	.1012	27.09	.0965	18.53	.0951	9.44	.0881	0
11	.435	.2001	164	.1045	27.17	.0984	18.44	.0963	9.51	.0912	0
12	.469	.2018	148	.1088	26.12	.1057	18.36	.1027	9.45	.0979	0
13	.466	.2021	149	.1092	27.18	.1043	18.58	.1015	9.55	.0964	0
14[1]	.471	.2025	147	.1125	27.57	.1086	18.93	.1063	9.71	.1000	0
15	.500	.2022	134	.1168	26.37	.1120	18.46	.1099	9.46	.1032	0
16	.533	.2036	122	.1223	25.43	.1189	18.09	.1159	9.28	.1094	0

[1]Green volume value is questionable.

efficient) the following equation was obtained:

$$\frac{\text{Ln } (I_0/I)}{x} = y \qquad (3)$$

The term y is usually referred to as the linear absorption coefficient (cm^{-1}).

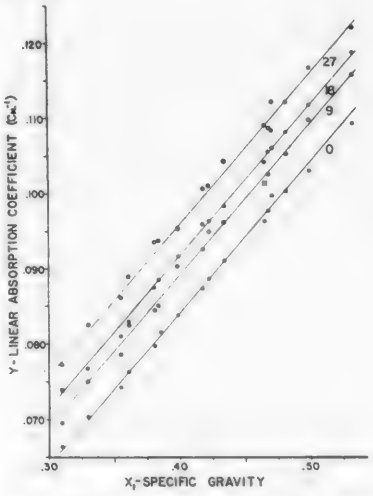

Fig. 3.—Plot of both basic data and fitted regression showing relationship between the linear absorption coefficient and specific gravity for four levels of moisture content.

Table 1 is a compilation of the average linear absorption co-efficient, y, calculated from the collected data by the use of Equation 3. The specific gravity, X_1, calculated from the oven-dry weight and green volume and the percentage moisture content, X_2, based on oven-dry weight are also shown in Table 1. Gross density (wood plus water), p, is defined as weight at test per volume at test. Volume at test measurements were not made, however, and specific gravity (oven-dry weight, green volume), X_1, and percent moisture content, X_2, were used in place of gross density, p.

Models for Specific Gravity Below Fiber Saturation Polts of y versus X_1 at four levels of X_2 are shown as points in Fig. 3. These plots indicate that the following model should adequately describe the data:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_2^2 + b_4X_2^3 \qquad (A)$$

The first terms of this model evaluates the ordinate intercept. Second and third regression coefficients evaluate the linearity of the relationship between y, X_1 and X_2. As previously mentioned, preliminary plots also indicated that the effect of moisture content, X_2, from oven-dryness to fiber saturation was not linear; therefore, the power terms were added to give an indication of the type and the amount of this non-linearity. A simpler model was also fitted to the date. This model is shown below:

$$Y = b_0 + b_1X_1 + b_2X_2 \qquad (B)$$

If model B were plotted in Fig. 3, the only change would be that the 0, 9, 18 and 27 percent moisture content lines would be evenly spaced.

Evaluation of the regression ceofficients for models A and B involves the inversion of a five by five and a three by three non-orthogonal matrix, respectively—a formidable task with a desk calculator. Therefore, the data presented in Table 1 (omitting the saturated condition) was punched on IBM cards and run through the necessary portions of the IBM 650 multiple regression program, thus giving the regression coefficients for models A and B as shown below:

$$Y = 0.0034 + 0.2018\,X_1 + 0.000892\,X_2 - 0.0000466\,X_2^2 + 0.0000011\,X_2^3 \qquad (A)$$

$$Y = 0.0039 + 0.2012\,X_1 + 0.000445\,X_2 \qquad (B)$$

Terms in the model were arranged so that the value they contribute to explaining the variation in y due to the measured parameters X_1 and X_2 may be tested. Analyses of variance shown in Tables 2 through 4 were used to test the merit of including the X_2^2 and X_2^3 terms in the model. The values for these analyses of variance were also obtained from the multiple regression computations.

The F test indicates that the omission of the X_2^2 and X_2^3 terms causes a significant loss in the ability of the model to represent the data.

The root mean square deviations, $S_{y\cdot x}$ values were 0.00116 and 0.00129 for Equations A and B, respectively. The $S_{y\cdot x}$ value for model B is slightly greater than that for model A. Thus it appeared that model A best represented the data collected. This model is valid only in the moisture content range from fiber saturation to oven-dryness. At higher moisture contents, a different phenomenon is prominent so this model is not valid. Discussion of a model that is valid in the higher moisture content ranges will be presented later.

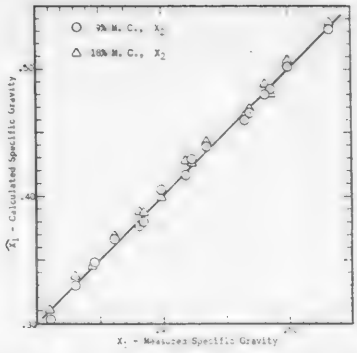

Fig. 4.—Comparison of specific gravity calculated from regression equation with specific gravity as measured by standard method (green volume).

Regression lines based on Equation A at 0, 9, 18 and 27 percent moisture levels are also shown in Fig. 3. The fact that no appreciable X_1X_2 interaction exists is aparent from the parallelism of the groups of plotted points. Thus a decrease of 9 percent in moisture content results in the same amount of decrease in the y reading for 0.30 specific gravity as in the y reading for 0.50 specific gravity. Yet, at 0.50 specific gravity, a 9 percent decrease in moisture results in the loss of two-thirds more water by weight than at 0.30 specific gravity (since moisture content is based upon oven-dry weight of the sample). If wood did not shrink, the change in y reading should be proportional to the weight of water lost rather than to the change in percent moisture content. Wood does shrink with the loss of moisture below fiber saturation, however, and this shrinkage in volume is proportional to the volume that was occupied by the removed water. Thus, for a given reduction in percent moisture content, wood of high specific gravity undergoes greater shrinkage since it loses a greater volume of water. As a result, gamma ray absorption is proportional to percent moisture content.

An indication of the accuracy by which specific gracity may be determined, when moisture content and linear absorption coefficient are known, is shown in Fig. 4. Specific gravity values X_1 were calculated from the measured moisture contents, X_2, (9 and 27 percent levels) and the linear absorption coefficients, y, from Table 1 by means of model A. As may be seen from Fig. 4, the agreement between these calculated values and the measured values, determined from oven-

Table 2.—ANALYSIS OF VARIANCE INCLUDING ALL TERMS

Sources	d.f.	Sums of squares	Mean squares
Regression	4	0.0227857	0.005696
Deviations	123	0.0001641	$S_{y\cdot x}^2 = 0.0000013$
Total	127	0.022950	
		$S_{y\cdot x} = 0.00116$	

Table 3.—ANALYSIS OF VARIANCE WITHOUT X^2_2 AND X_2^3

Sources	d.f.	Sums of squares	Mean squares
Regression	2	0.0227424	0.011371
Deviations	125	0.0002074	$S_{y\cdot x}^2 = 0.0000017$
Total	127	0.022950	
		$S_{y\cdot x} = 0.00129$	

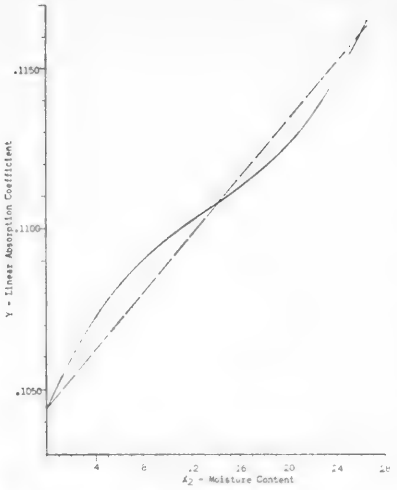

Fig. 5.—Effect of wood moisture content on linear absorption coefficient.

dry weight, green-volume measurements, is very good.

The linear absorption coefficients shown in Table 1 and Fig. 3 compare favorably with those measured by Parrish (5). For example, Parrish found the linear absorption coefficient for sugar pine (specific gravity 0.36) at a source energy of 47 Kev to be 0.095 $cm.^{-1}$ Fig. 3 indicates that, for yellow poplar of specific gravity 0.36 and a source energy of 47 Kev, a linear absorption coefficient of 0.080 cm^{-1} was obtained. These values indicate good verification even though this comparison involves two different species of wood.

Moisture Content Measurements Below Fiber Saturation: Another feature that should be noticed in Fig. 3 is the unequal spacing between the levels of moisture content, X_2. This is more clearly illustrated in Fig. 5, in which the theoretical linear absorption coefficient, Y, is plotted against moisture content, X_2, for a given specific gravity, X_1, in this case 0.50. The broken line represents the linear relationship defined by Equation B, while the sigmoid curve is derived from Equation A. The maximum error in estimating y from model B instead of model A is 0.0012 $cm.^{-1}$

A probable explanation for this curve shape comes from close scrutiny of the relationship between tangential shrinkage and moisture content, which was shown by Wilson (8) to be a sigmoid-shaped curve as depicted in Fig. 6. Usually a straight line relationship is assumed for most purposes, as shown by the broken line in Fig. 6. When accurately measured, however, the rate of shrinkage is lower from 0 to 9 percent moisture content, due to the compression of the water, and from 18 to 27 percent moisture content, because large test pieces were used, than it is from 9 to 18 percent moisture content. Thus the rate of change in the linear absorption coefficient is greater when the rate of shrinkage is less. This relationship follows the tangential shrinkage curve rather than the volumetric or radial shrinkage one because the radial thickness, x, in equation 2 removes the effect of radial shrinkage.

Moisture Content Measurements Above Fiber Saturation: In the region from fiber saturation to complete saturation, no method of obtaining uniform moisture distribution is known, so data were not collected in this region.

Wood does not begin to shrink until its moisture level approaches the fiber saturation region. Therefore, the relationship between linear absorption coefficient, y, and moisture content, X_2 above fiber saturation, at given specific gravities, X_1, should be linear and may be represented by the model shown below.

$$Y = r_0 + r_1X_1 \qquad (C)$$

Data were available for the two extremes of this region, fiber saturation (assumed to be 27 percent moisture content) and saturation. By using the above-mentioned assumption of linearity in this region in conjunction with the data available, it was possible to calculate the slope $\Delta y/\Delta X_2$

This slope was obtained by subtracting Y values (as obtained with Equation A), for 27 percent moisture content, from the measured y values for the saturated moisture contents, as listed in Table 1, and then dividing this Δy increment by its appropriate moisture content increment, ΔX_2. These slopes were then plotted against their corresponding specific gravities, X_1. A precise linear relationship resulted, so a least-square linear regression was fitted. The regression model and equation were as follows:

$$r_1 = h_0 + h_1X_1 \qquad (D)$$

and

$$r_1 = 0.000051 + 0.001507\ X_1$$

Substitution of this expression for r_1 into Equation C resulted in the following expression:

$$Y = r_0 + h_0X_2 + h_1X_1X_2 \qquad (E)$$

Fig. 6.—Tangential shrinkage as a function of wood moisture content.

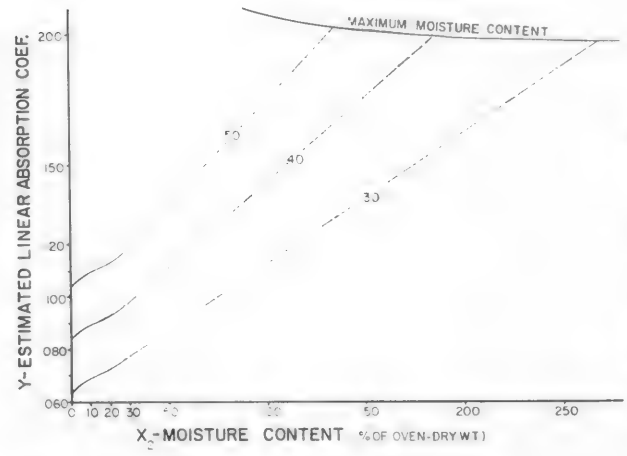

Fig. 7.—Summary graph showing the relationship between linear absorption coefficient and moisture content for three levels of specific gravity.

Table 4.—ANALYSIS OF VARIANCE FOR THE EFFECT OF ADDITIONAL DUE TO X_2^2 AND X_2^3

Sources	d.f.	Sums of squares	Mean squares
Additional for X_2^2 and X_2^3	2	0.0000433	0.0000216
Error	123	0.0001641	0.00000133

$$F = \frac{\text{Additional M. S.}}{\text{Error M.S.}} = \frac{0.0000216}{0.00000133} = 16.62,$$ with 2 and 123 degrees of freedom is significant beyond the 1 percent level.

The value for r_0 was obtained by equating model A to model E at 27 percent moisture content. This resulted in the following expression:

$$Y = C_0 + C_1X_1 + C_2X_2 + C_3X_1X_1 \quad (F)$$

and

$$Y = 0.00128 + 0.1611\ X_1 + 0.000051\ X_2 + 0.001507\ X_1X_2$$

Thus a model was obtained for the moisture content region from fiber saturation to saturation. Models A and F were evaluated in the moisture content regions in which they are valid. These evaluations were done at three levels of X_1, 0.05, 0.40, and 0.30. A plot of Y versus X_2, for three levels of X_1 mentioned above, was made and is shown in Fig. 7.

The X_1X_2 interaction is present in model F because above fiber saturation there is virtually no swelling to counteract the effect of adding a larger weight increment of water for a given percentage increase in moisture content for a piece of wood of high specific gravity than for one of low specific gravity.

Conclusions

1. When the gamma ray attenuation, the thickness, and the moisture content of a piece of wood are known, its specific gravity may be determined non-destructively and rapidly with a high degree of accuracy.

2. When the gamma ray attenuation, the thickness, and the specific gravity of a piece of wood are known, moisture content may be determined in its complete range.

3. The presence of shrinkage in wood below fiber saturation requires that separate gamma ray absorption models be used above and below fiber saturation.

4. The linear absorption coefficient closely follows the rate of shrinkage from fiber saturation to oven dryness.

Recommendations and Suggestions for Further Study

1. A thin window crystal would improve the accuracy with which gamma ray attenuation measurements could be made.

2. An area or button-type source instead of a point source, as used in this study, should improve the correlation between volume measured by the radiation method and that determined by the standard methods.

3. If a Pb-210 source is used, the source should be thin and backed with a low-density material such as aluminum or plastic. This will lower the "bremsstrahlung" produced by the Bi-210 daughter.

4. Further studies should include an evaluation of the effects of grain direction, species, and moisture content above fiber saturation.

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SIMPLIFIED DATA-HANDLING TECHNIQUES

For Particle Board and Hardboard[1]

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The Borden Chemical Co.
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THE STUDY OF PROCESS VARIABLES involved in the manufacture of particle board and hardboard is dominated by two main factors: the large dependence of physical properties on the density of the board, and the non-homogeneous nature of the product, which leads to a wide dispersion in the test data. This dispersion requires that a large number of measurements be made and averaged to give representative numbers that can be treated with some degree of statistical confidence.

Under these conditions, it is important to reduce to a minimum the work involved not only in preparing and testing samples, but in the mechanical treatment of the test data. Such operations as multiplying each test number by a constant are redundant from a statistical point of view, and even the labor of tabulating data or of plotting it in graphical form can consume enormous amounts of time. Mechanical devices such as nomographs, specially constructed slide rules, and high-speed computors have been used to speed the processing of test data.

The purpose of this paper is to present some simplifying techniques that can be used to facilitate data handling in any form of physical testing, and to illustrate them with some examples of their application to particle board and hardboard. The work on application in this field is continuing, and indications are that these techniques will be equally useful in both laboratory work and production control.

The Author: Murray Carroll graduated in chemistry from the Univ. of British Columbia, and earned his Ph.D. in physical chemistry from McGill Univ. with research at the Pulp and Paper Institute of Canada.

[1] Presented at the Winter Meeting of the Pacic Northwest Section, FPRS, Feb. 9, 1960, in Bellingham, Wash.

Flexural Strength

The choice of flexural strength as a measure of board strength cannot be criticized, since it requires an absolute minimum of sample preparation, and the test values can be obtained quickly on a relatively simple and inexpensive test device. The measured value is customarily converted to the form of

Some algebraic transformations are described by which standard expressions of the relation between test properties and density may be highly simplified. These procedures may sometimes reduce the work involved in processing test data, primarily by eliminating statistically redundant operations. Examples are given in which flexural and internal bond strength were represented by simplified functions independent of variations in board density. Both laboratory and production-control test data may possibly be processed by these techniques.

modulus of rupture (MOR). The variation in MOR attributable to the variation in the density (D) of the sample may be determined analytically by some form of regression analysis, or by plotting the corresponding values of MOR and sample density graphically in what is frequently, and very descriptively, referred to as a "scatter diagram". From this graphical plot, an estimate of the relationship between the two properties may be obtained by "eyeballing" a best-fit line.

Analytically, if it is assumed that the relationship is linear (at least as a first approximation), the algebraic form is

(1) $MOR = K\ D + C$

or the equivalent form

(2) $MOR = K(D - D_o)$

where D_o is the (extrapolated) value of density when MOR = O.

For a homogeneous material, the relationship of MOR to the measured values of breaking load P, test span s, sample width b, and sample thickness d, is given by the relationship.

(3) $$MOR = \frac{3Ps}{2bd^2}$$

and the sample density is given by the relationship

(4) $$D = \frac{w}{bdLQ}$$

where L is the sample length, and Q is a conversion factor used to obtain D in the desired units.

If equation (2) is expanded into detail form

(5) $$\frac{3}{2}\frac{Ps}{bd^2} = K\frac{(w - w_o)}{bdLQ}$$

it can be seen that, by standardizing the sawn dimensions as well as the test span, we may regroup the items in equation (5) into the form

(6) $$\frac{P}{d} = \frac{K}{c}(w - w_o)$$

where $$c = \frac{3\ L\ Q\ s}{2}$$

from which it is evident that the values of K and D_o for use in equation (2) may be determined from a plot of P/d against w, since the value of D_o may be obtained by putting the found value of w_o into equation (4). A considerable saving in the labor of calculation may be realized by this technique of simplification and standardization. The standard sample size may be obtained through the use of interchangeable preset guides on a table saw, which hold cutting tolerances of ± 0.01 inch and require only infrequent adjustment to compensate for wear or loss of set on the saw teeth.

The relationship shown in equation (2) or its simplified form, equation (6), was found to be inadequate to describe the behavior of screen-back hardboard. In this material, the board thickness is rather poorly defined, and in 1/8 inch board an error of a few thousandths of an inch represents a substantial percentage error. Indeed, it seemed doubtful that the relationship $P/d^2 = constant$, which is implicit in equation (3), would be applicable to this type of board. A search was therefore made for a relationship between the measured variables P and w, which could be used to correct the data for at least minor deviations from a working level. It was found that by assuming the variation in d to be negligible (or at least accepted as experimental error), the data could be fitted with a relationship of the linear form

(7) $P = \text{constant}\ (w - w_o)$

Further study showed that a better description of the data could be obtained from a simple form

(8) $P/w^2 = \text{constant};\ (w_o = O)$

in which the values of P and w are obtained under test conditions in which $b = constant$, $L = constant$, and $s = constant$.

Actually, the best fit was found with an exponent form $P/w^{2.3} = constant$ but the improvement over the simple form of equation (8) was not sufficient to warrant the additional complication of working with the non-integral exponent. The general form of equation (8) is

(9) $P = \text{constant}\ (w - w_o)^2$

which can be rectified to the form

(10) $\sqrt{P} = \text{constant}\ (w - w_o)$

and treated in the same manner as was equation (6) except that in this case the dependent variable is $\sqrt{P}$ instead of P/d.

A bit of algebraic manipulation will show that the form of equation (8) may also be obtained from an assumed relationship of the form

(11) $MOR = K^2\ D^2;\ (D_o = O)$

since in the expanded form

(12) $$\frac{3}{2}\frac{Ps}{bd^2} = K^2\frac{W^2}{b^2d^2L^2Q^2}$$

the thickness term d^2 cancels out, leaving the form

(13) $$P/w^2 = K^2/C^2 \text{ where } C = LQ\sqrt{3/2bs}$$

and substitution of the value of K^2 obtained from equation (13) into equation (11) yields

(14) $$\frac{MOR}{D^2} = C^2\frac{(P)}{w^2}$$

While it is possible to obtain equation (8) from equation (11), however, it is not possible to go in the reverse direction without introducing additional assumptions regarding the applicability of the MOR relationship to the board in question. There are no such restrictions on the form P/w^2, since it deals only with the *measured* values of P and w, and expresses a purely empirical relationship between them. The transformation, $\sqrt{P}/w$, is even more descriptive, since the value of $\sqrt{P}$ is a measure of board strength, and the value for w is a direct measure of the material cost of the board per unit area.

If the correspondence implicit in equation (14) is established, then (14) may be transformed into

(15) $$D_c = \sqrt{\frac{C}{MOR}}\ \frac{w}{\sqrt{P}}$$

where D_c represents a calculated value of board density. If we define a minimum value for MOR that we wish to maintain in a manufacturing operation, and measure the value of $w/\sqrt{P}$ on the boards being produced, equation (15) permits us to calculate a value for D_c which is the minimum value of board density that must be maintained to maintain the specified minimum value of MOR. If the actual value of board density D is obtained by direct measurement, such as from the weight and caliper of the entire (press size) board, then the relationship between D and D_c is a measure of process control. If D_c is greater than D, the flexural strength of the board will be below specification. If D is greater than D_c, the material cost of the board is higher than is required to meet the strength specification. In this latter case, correction can then be made by lowering the operating level of board density (or possibly by a reduction in the level of resin binder) to maintain a minimum level of material cost.

The simplified form $P/w^2 = constant$ will not be applicable in all cases. For some it may be necessary to use a more general form

(16) $$\frac{P}{(w - w_o)^n} = \text{constant}$$

or the rectified form

$$(17)\quad \frac{(P)^{\frac{1}{n}}}{(w - w_o)} = \text{constant}$$

to obtain the best description of the data.

In one case, which involved the flexural strength of a 1/4 inch wet-process hardboard produced commercially, it was found necessary to use a form $P/(w-w_o)$ to obtain the best description of the data. For this board, a plot of MOR against D was distinctly nonlinear. In another case, a laboratory-made 1/8 inch wet-process hardboard, the function P/w^3 gave the best description of the within-board data. Note that this form implies that the breaking load of the board samples is following a relationship $P/d^3 = constant$ rather than the relationship $P/d^2 = constant$, which is implicit in the standard form shown in equation (3). For cases of this sort, the data may be viewed from a different perspective. If we define a standard condition using the nominal values of board thickness and board density (say d = 0.125, and D = 1.05 gm/cc), then for the given sample size (saye 2 by 8 inches) we can determine a standard value w_s for the weight the sample would have at the defined thickness and density. If the function $P/w^n = constant$ has been found to be valid over a range of values of w that includes the value w_s, then the test data can be placed in the form

$$(18)\quad P_s = \frac{P}{w^n}(w_s)^n$$

if b, L, and s are constant.

Here the P_s values are all estimates of what the breaking load would have been if all the samples had the same standard thickness and density; that is, it represents a target value. Since w_s is a constant value, it follows that the P/w^n values are in themselves a measure of P_s, since they differ only by a constant of proportionality, and the percentage variation in the P/w^n values will be the same as the percentage variation in the P_s values.

It is emphasized that the technique of curve-fitting is not necessarily concerned with the "actual" relationship between MOR and board density, but only with those forms which best describe the relationship between the *measured* variables such as breaking load and sample weight, with particular interest in those forms which simplify the labor of measurement and calculation. The standardization of test dimensions represents an immediate saving, and any function in which the value of w_o can be taken as zero eliminates the need for graphical analysis or regression analysis to predetermine w_o.

A third technique for labor saving can be realized in the handling of grouped data. Frequently the "within group" variation of test values is of minimum interest, and although a number of samples may be taken from one board, what is desired is an average value that represents the entire board. If one uses the form of equation (8) and a group of say 10 samples, the desired value is

$$(19)\quad \frac{1}{10}\sum_{i=1}^{10} K_i = \frac{1}{10}\sum_{i=1}^{10}\frac{(P_i)}{(w_i^2)}$$

The number of operations involved in determining the value are

10 measurements of P_i entered on a printing adding machine;

10 measurements of w_i entered on a printing adding machine;

10 calculations w_i^2;

10 calculations of P_i/w_i^2 entered on a printing adding machine;

1 calculation to obtain the average value of P_i/w_i^2.

This represents an average of 4.1 operations per sample. If the weighing device is fitted with a non-linear scale calibrated in units of w^2, the operations are reduced to an average of 3.1 per sample.

A further saving in labor may, in many cases, be realized by means of an approximation of the sort

$$\frac{1}{n}\sum_{i=1}^{n}\left(\frac{P}{w^2}\right)_i \doteq \frac{\sum_{i=1}^{n} P_i}{\sum_{i=1}^{n}(w^2)_i}$$

This relationship would be exact if all the values of $(P/w^2)_i$ are identical. In practice these values are not identical, but differ from a common value (the mean) by small amounts. If these differences are small, the approximation shown in equation (20) is a relatively good one. With test data obtained in our laboratory, the difference between the values obtained from the two sides of equation (20) is usually less than 1 percent, and in comparative experiments such as the comparison of resin efficiency between two resins, the percentage relationships between the efficiency values determined by the alternative routes differ by an even smaller amount. No blanket condition can be given under which the approximation shown in equation (20) is valid; the data in question should be tested by trial, and the magnitude of the discrepancy examined.

If the validity of the approximation may be accepted, then the use of equation (20) in our previously described scheme involving 10 samples

What This Research Means

This paper is an illustration of the use of the techniques of applied mathematics to the processing of physical test data obtained from hardboard and particle board. Application of the basic ideas and techniques can result in as much as a tenfold reduction in the labor of acquiring and processing test data, as compared to the classical approaches to data handling. The examples given are concerned with the correction of the test data for assignable variation arising from uncontrolled variation in the density of manufactured board. The basic idea, however, may be extended to other variables. Moreover, by the use of curve-fitting techniques, it is possible to simplify statistical analysis by replacing a two-factor regression analysis with a single-factor analysis.

The work also deals, to a small extent, with the basic philosophy of physical testing. The basic elements of physical testing are the actual measured values. When we progress from these to the stage of thinking about the relationships between these measured values, theoretical relationships such as the commonly used modulus of rupture relationship are of considerable value as guides to our thinking, but they are not a substitute for thinking, since they may involve assumptions that may not be well met by the material being tested. They may serve well as a first approximation, but must be reexamined when the time comes for a second approximation, or the hidden assumptions can lead us to false or meaningless conclusions. The use of approximations is unescapable, and applied mathematics deals specifically with such things. However, the principle of Occam still applies: the path of safety and progress lies in simplicity of form and a minimum of assumptions.

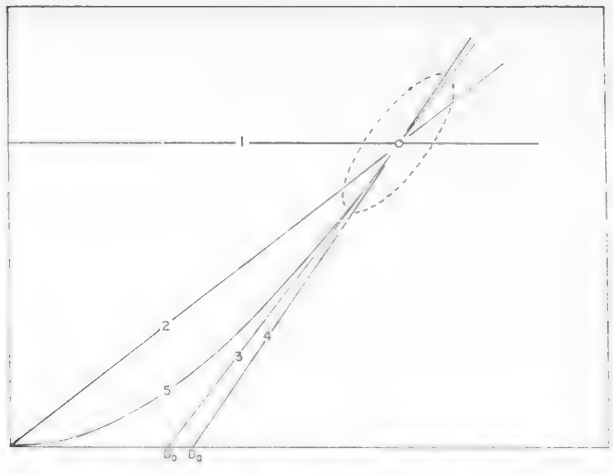


Fig. 1.—Five forms in which the relationship between MOR and board density may be represented with varying degrees of approximation.

eliminates the 10 individual calculations of P/w^2, and the average number of operations per sample is reduced to 2.1.

If the non-linear scale is used on the testing machine to give values of the test load in units of $\sqrt{P}$, we may express our data in the form $\sqrt{P}/w$ (cf. Equation 10), and obtain our value of Σw_i by a single weighing of the entire subgroup of samples. For our example, in which the subgroup size is 10, this eliminates 9 more operations and leaves us with

10 measurements of $\sqrt{P_i}$ entered on a printing adding machine to give $\Sigma\sqrt{P_i}$;

1 measurements of Σw_i;

1 calculation of $\dfrac{\Sigma\sqrt{P_i}}{\Sigma w_i}$.

This procedure, which also involves the approximation relationship shown in equation (20), gives us a net value of 1.2 operations per test sample.

The usual technique of expressing the data in the form of MOR and density and using graphical analysis or regression analysis may involve 15 to 30 operations per test sample operations such as measuring, recording, testing, calcuation, and plotting graphically.

These techniques are designed to reduce the within-board data quickly to average board data so that replication may be had at the between-board level, and the quality of the data is substantially improved.

Applicability

The value of these simplification techniques is to some extent dependent on experience, as well as their use in appropriate experimental designs. For comparisons of statistically defined significance, the least amount of replication is required when the error term is reduced to the smallest possible value. But practical considerations enter into a sampling and testing pattern, and an optimum pattern takes into account not only the value of a given operation, but the cost of that operation. Statistical tools such as analysis of variance are valuable in determining optimum sampling, the cost figures are readily attached to the various tests that are made on the samples. A frequently neglected factor, however, is the cost of processing large masses of data; for on optimum procedure, the data-handling techniques must be an integral part of the overall optimum pattern of proceeding from product to conclusion. Just as 100 percent sampling is in most cases economically unjustifiable, 100 percent accuracy in representation of data may be uneconomical.

A simple example of this is shown graphically in Fig. 1, in which a hypothetical plot of MOR against density is shown in outline as the familiar elliptically shaped "scatter" diagram. The various lines drawn through the mass center of the plot show various degrees of representation of the data. Line 1, a horizontal line, is based on the assumption that there is no correlation between MOR and density, and that all of the deviations from the line are experimental error. Line 2, drawn from the origin, is a second estimate of the relationship between the two variables, of the form

$$(21)\quad \frac{\text{MOR}}{\text{D}} = \text{constant} = k_2$$

This is still not a good estimate, since part of the dispersion in the k_2 values will be the result of regression, but it represents a considerable improvement over the representation obtained from line 1.

Line 3 represents the "best fit" line such as would be obtained from a "least squares" analysis of the data. This line is described algebraically by the formula

$$(22)\quad \frac{\text{MOR}}{(\text{D}-\text{D}_o)} = \text{constant} = k_3$$

A great deal of computation may be involved in the formal determination of D_o, and the confidence limits on the value of D_o may be quite broad. Thus by choosing an arbitrary intercept value D_a, perhaps obtained from previous experience with this type of material, the representation

$$(23)\quad \frac{\text{MOR}}{(\text{D}-\text{D}_a)} = \text{constant} = k_4$$

can be a very good approximation, particularly if the value of D_a lies within the confidence limits on D_o.

Line 5 shows an alternative representation of the data by a parabola with the vertex at the origin. This eliminates the need for an additive constant, and gives us the simple form,

$$(24)\quad \frac{\text{MOR}}{\text{D}^2} = \text{constant} = k_5$$

which, as has been shown earlier, greatly facilitates the work of computation.

The simple test for "goodness" of fit is the calculation of the k_i values from the representative equation such as equation (23). If the value of D_a is chosen correctly, there should be no residual correlation between the values of k_i and the corresponding values of D_i. This can usually be seen from a comparison of the tabulated values of k_i and D_i. If the values of k_i show a consistent increase or decrease as the values of D_i increase, the value for D_a is a poor choice.

Experimental Application

The first application of the simplified data-handling technique was to laboratory-made screen-back hardboard. The main interest in this application was a comparison of resin efficiency between various phenolic resins, under "constant" conditions of board manufacture. These "constant" conditions were obtained by standardizing the conditions of board manufacture, and contained a considerable element of operator skill. The primary difficulty in obtaining uniform boards lay in the difficulty in felting a uniform mat. This non-uniformity showed up not only as density variations within the board, but as corresponding thickness variations. The experimental design was based on the assumption (not previously established) that the function P/w^2 could be used to correct the data for *minor* deviations from an operating point. The experimental design was based on a "spray" unit in which the resin was applied to sufficient fiber (by spray-

ing) for two boards at each of two press temperatures. The average flexural strength of each board, represented by the function P/w^2 as independent of density variations, defined the replication in the felting and pressing operation. The different resins were applied at the same resin level, nd every effort was made to maintain uniform manufacturing condition.

After the boards were pressed, they ere sampled uniformly to give five 1 y 14 inch strips. Each of these strips as broken progressively at a 3-inch an (1/8-inch board) to give a total f five flexural tests per strip. These e values were averaged to give an stimate of P for the strip. This value as combined with the strip weight to ive a P/w^2 value for the strip, and e five such values were averaged to ve a value of P/w^2 to represent the oard. These board average values are bulated in Table 1.

The boards were made in the order hown in the table, and the total experiment extended over several hours operation. It is quite evident from the data that the between-board replication improved as the day wore on, which indicated that the operator was becoming increasingly skillful. Resins A, B, C, and D, were experimental resins that were to be compared to the standard production resin E. None of the experimental resins match the production resin, although the differences are only on the order of 5 percent in the P/w^2 values. If we assume that equation (14) is valid, this implies that a 5 percent difference in MOR values would also be found. The actual magnitude is relatively unimportant, since we are dealing with a model of a production process, and a 5 percent difference in resin efficiency in the model might show up as a much larger difference in the actual production process on which our model is based. For the business of resin development, the ranking of the various resins obtained from the laboratory process is sufficient. The quantitative correlation between the laboratory model and the production process can be established subsequently by plant scale trials.

The data summary shown in Table 1 illustrates the simplicity of this technique of data handling within an experimental design that minimizes the spread in board density. The desired information (relative resin efficiency) was obtained with a very minimum of calculation, and without the need for a thickness measurement on the samples. In later work of this type, we have been using the function $\sqrt{P/w}$ for the reasons described previously.

The relative success of this approach in hardboard led to an examination of its applicability to medium-density particle board. In this material, measurement of thickness represents no real problem other than the time consumed in the measurement. Previous work in this laboratory indicated that the relationship between MOR and density in particle board was linear over a wide range of density. Analysis of the test data from 20 boards yielded a description.

(25) $\text{MOR} = 5563(D - 0.365)$; where $0.57 \text{ gm./cc} \leq D \leq 0.73 \text{ gm./cc}$ which by standardization could be reduced to the form of equation (6). Yet the function P/w^2 appeared to work very well over narrow ranges of board density. To test this function, six boards were made under standard conditions of manufacture, which covered a range of board density from 0.54 gm/cc to 0.80 gm/cc. After they were conditioned, the boards were sampled to obtain eight flexure samples, and from these the board average value of P/w^2 was obtained. For the purpose of illustration, these P/w^2 values were converted to the form MOR/D^2 by means of equation (14), and the individual values of MOR and density were determined separately. Fig. 2 shows the plot of MOR against density for the six values. The data are very nicely fitted by a straight line, which, when extrapolated to the abcissa at 0.395 gm/cc, gives the relationship

(26) $$\frac{\text{MOR}}{(D - 0.395)} = \text{constant} = K_L;$$
where $0.54 \text{ gm/cc} \leq D \leq 0.80 \text{ gm/cc}$

The same data were also plotted as MOR against D^2 in Fig. 3. In this case, a straight line from the origin (assuming D_o = zero) does not fit all the points, but does give a representation of the four boards made at the higher densities above 0.60 gm/cc. Within this restriction it is possible to represent the data from the four high density boards by the form

(27) $$\frac{\text{MOR}}{D^2} = \text{constant} = K_Q;$$
where $0.65 \text{ gm/cc} \leq D \leq 0.80$ gm/cc

Another possibility would be to represent the data by a linear equation of the form

(28) $$\frac{\text{MOR}}{(D - 0.365)} = \text{constant} = K_a$$

where the value for D_o was chosen on the basis of the previous experiment, which resulted in equation (25).

Table 2 shows the tabulated values of MOR K_L, K_Q, and K_a for all six density values. Since the quadratic approximation obviously did not apply to the low-density boards, the comparison of "goodness" of fit is made on the last four data points only. This comparison is obtained by determining the standard deviation of the K_1 values in each case and converting them to the form of coefficient of variation (ν) to show relative values. The position of the decimal point in the various values of K_L, K_a and K_Q is not shown, since it is not necessary to the comparison.

The restriction of the analysis to the last four points is justifiable on practical grounds, since commercially there is little interest in board densities below 0.60 gm/cc. The data in Table 2 illustrate concretely the hypothetical description of curve-fitting that was pictured in Fig. 1. Column 2 shows the dispersion of the uncorrected MOR values (of line 1 in Fig. 1). The K_L values in column 2 of the table show the improvement obtained from the "best fit" line; (of line 3 in Fig. 1). The K_a values are obtained by aribitrarily assigning a value of 0.365 gm/cc on the basis of previous experience.

The relationship shown in equation (25) from which this intercept value was drawn was determined four years ago on boards made from a completely different particle, and with press conditions that differed in every respect (temperature, close time, total press time) from the conditions used in the present work. Yet the use of the arbitrary value for the intercept D_a gave as good a representation of the four values as did the value that was determined from plotting the data graphically and drawing a "best fit" line.

Table 1.—APPLICATION OF THE SIMPLIFIED FUNCTION P/w^2 TO THE EVALUATION OF THE FLEXURAL STRENGTH PRODUCED BY FIVE PHENOLIC RESIN BINDERS IN LABORATORY MADE SCREENBACK HARDBOARD

Resin	Spray	Board	T_1 °F. P(lb.)	T_1 °F. w(gm)	T_1 °F. $(P) \times 10^3$ (w^2)	T_2 °F. P(lb.)	T_2 °F. w(gm)	T_2 °F. $(P) \times 10^3$ (w^2)
A	1	1	17.2	29.8	192	20.6	28.9	246
		2	18.4	30.2	169	21.2	28.8	256
B	1	1	13.7	29.6	157	23.5	29.7	267
		2	14.9	29.8	168	21.7	29.1	257
C	1	1	15.3	28.8	175	20.6	28.8	248
		2	16.8	28.6	181	20.7	28.6	253
D	1	1	16.8	29.8	176	21.4	29.3	249
		2	17.4	31.3	178	20.6	28.8	248
	2	3	15.2	29.4	177	21.6	29.5	248
		4	----	----	----	----	----	----
E	1	1	17.0	30.1	187	21.8	28.8	263
		2	15.9	29.8	180	21.5	28.9	257
	2	3	17.6	30.7	188	21.6	28.8	261
		4	16.8	29.8	189	22.9	29.4	264

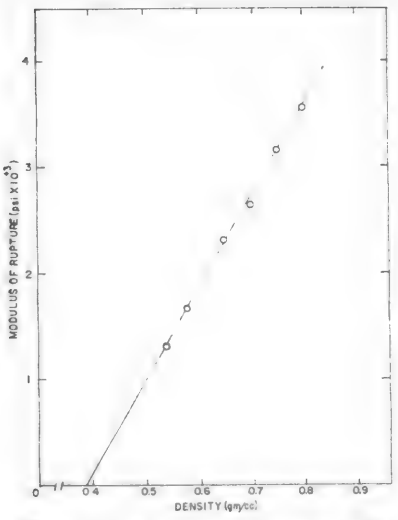


Fig. 2.—The relationship between MOR and board density for six particle board samples prepared in the laboratory.

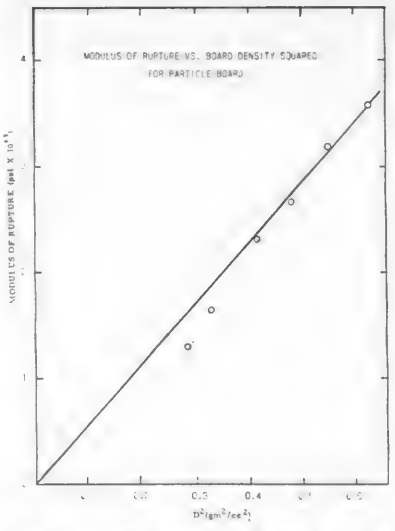


Fig. 3.—The relationship between MOR and the square of the board density for six particle board samples prepared in the laboratory.

Moreover, the dispersion on the K_Q values shows that an equally good representation of the data was obtained from the quadratic representation (cf. line 5 in Fig. 1.). Thus, if application is restricted to the higher density range, we are pragmatically justified in using the quadratic representation to take advantage of the labor-saving features of the P/w^2 form of data representation.

Further application is shown in Table 3, in which the samples from a plant trial were handled by a simplified technique. The trial is a comparison of two resins under conditions in which the total press time was progressively shortened. Board samples were taken at the time intervals shown in column 1. These samples were each cut to yield nine 3 by 14 inch flexure test samples. The P/w^2 values from these nine tests were averaged to give the board average values shown in column 4 of Table 3, and the average value for each press condition is given in column 5. The figures given in columns 6 and 7 refer to the internal bond measurements, which will be discussed in a later section and need not concern us at this time.

The density range of these samples was 0.67 to 0.73 gm/cc. The replication of the values of P/w^2 within a press condition is excellent, and the press-condition values of P/w^2 describe very well the course of the trial. Although uniform sampling was not maintained, the relative efficiency of the two resins is reasonably well established.

The conditions of the experiment are such that an extremely precise analysis is not warranted. The comparisons made between resins and between press conditions are all based on the assumption that the manufacturing conditions preceeding the press remained essentially unchanged over a period of four hours. The uncertainty in this assumption is translated into an uncertainty in the conclusions drawn from the test data. The essential point is that it is possible to visualize the entire course of the experiment without thinking in terms of MOR or density.

The question of whether the board properties held up at the shortest press times is not fully answered by the flexural strength data, but requires consideration of the changes that took place in the internal bond strength in the center of the board, which is the region furthest removed from the source of the heat required to cure the urea formaldehyde resin binder. This aspect will be discussed in the next section.

Determination of Internal Bond

The value of internal bond (tension perpendicular to the face in psi) complements the information obtained from a flexural test, since the latter tends to measure surface properties. The internal bond strength (IB) is determined by gluing a 2 by 2 inch sample to supporting blocks and pulling the sample apart in a direction perpendicular to the face. This property is also highly dependent on the board density. The simplest description of this relationship is the linear form

$$(29)\quad IB = K(D - D_0)$$

If B is the breaking load obtained from a sample of area $A = bL$ then expansion of equation (29) yields

$$(30)\quad \frac{B}{bL} = \frac{K(w - w_o)}{bdLQ}$$

which reduces to

$$(31)\quad \frac{Bd}{(w - w_o)} = \frac{K}{Q}$$

Here standardization of the sawn dimensions is not required, since they do not enter into the relationship given in equation (31). Also, there is no form of polynomial curve-fitting that would eliminate the thickness variable as was accomplished for the flexural strength relationship. The basic problem in handling data of this sort is to determine an appropriate value for w_o in equation (31). In Fig. 1 it was shown that the form $Y/X = constant$ represents a first approximation to a relationship between Y and X (line 2 in Fig. 1). To test this approximation, the six boards referred to in Table 2 were sampled to yield 10 internal bond test samples per board. The data from these within-board samples were converted to this form and averaged to obtain a board average value. These values are tabulated in Table 4.

Table 2.—AVERAGE FLEXURAL STRENGTH DATA FROM SIX PARTICLE BOARD SAMPLES PREPARED IN THE LABORATORY

Density gm/cc	MOR psi	K_L	K_a	K_Q
0.54	1260	870	721	433
0.58	1640	887	763	488
0.65	2340	902	821	554
0.70	2622	849	783	535
0.75	3144	884	817	559
0.80	3540	874	814	553
Avg. 0.70	2911	877	808	550
ν		18.3%	2.5%	2.2%	1.9%

The data from the four high density boards are shown in four forms of algebraic representation (cf lines 1, 3, 4, and 5 of Fig. 1). The coefficient of variation (ν) shows the "goodness of fit" associated with each representation.

Table 4.—INTERNAL BOND TEST DATA FROM SIX PARTICLE BOARDS PREPARED IN THE LABORATORY

Board density gm/cc	Board average Bd/w
0.54	12.3
0.58	14.2
0.65	13.4
0.70	14.3
0.75	14.4
0.80	14.4

The test data are expressed in the simplified form Bd/w (independent of density variation).

The uniformity of the values of Bd/w indicates that the choice of $w_o = zero$ was a very good approximation, and the internal bond strength of

these boards may be very well represented by the simple function

$$(32)\ \mathrm{Bd/w} = \text{constant} = \frac{K}{Q}$$

or the correlative form

$$(33)\ \frac{IB}{D} = K = Q\frac{(Bd)}{(w)};\ \text{where}$$

$0.58\ \text{gm/cc} \leq D \leq 0.80\ \text{gm/cc}$

in which the density range below 0.58 is excluded because of the lack of agreement of the *Bd/w* value for the board made at 0.54 gm/cc.

With this function to describe the internal bond in a form independent of board density, the data shown in columns 6 and 7 of Table 3 may be used to complete the picture of the plant trial. These data show that, while the flexural strength of the board held up at the short press times for both resins, there is evidence that the internal bond started to fall off at the shortest press times used in each case. In view of the replication of the *Bd/w* values, the sampling at the shortest press time conditions is inadequate to permit a firm conclusion as to the minimum permissible press time in each case.

Table 3.—FLEXURAL STRENGTH AND INTERNAL BOND STRENGTH DATA FROM A PLANT TRIAL WITH TWO UREA FORMALDEHYDE RESIN BINDERS

Time	Total Press Time min.	Press Temp. °F.	$P/w^2 \times 10^5$ Auto-Set 31C	Avg.	$Bd/w \times 10^2$	Avg.
1055	8¼	300	162.3		643	
1100	"	"	161.4	162	698	688
1114	"	"	161.3		723	
1132	7¾	315	161.1		661	
1141	"	"	161.5	162	691	692
1148	"	"	163.5		725	
1156	6¾	335	161.5		720	
1206	"	"	166.3	166	700	733
1214	"	"	169.2		788	
1229	6¼	335	160.9		752	
1235	"	"	158.0	159	689	719
1245	"	"	159.0		716	
1255	5¾	335	174.0	174	746	746
1301	5¼	335	165.0	165	651	651
			WW-22			
1329	8¼	300	143.0		660	
				148		660
1354	"	"	152.0		660	
1402	7¾	315	166.0		741	
				165		720
1412	"	"	163.0		699	
1420	6¾	335	157.0		668	
				154		620
1430	"	"	151.0		591	
1436	6¼	335	152.0		605	
				151		588
1446	"	"	150.0		570	
1457	7¾	300	150.5	151	556	556

Flexural strength data are shown in the simplified form P/w^2 (independent of density variation). Internal bond data are shown in the simplified form Bd/w (independent of density variation).

Summary and Conclusions

An attempt has been made to show the potential value of some simplified data-handling techniques in the analysis of physical test data. Application of these techniques has been illustrated for flexural strength testing in the case of particle board and hardboard, and the measurement of internal bond strength in particle board.

The four techniques that have been described are:

1. Algebraic transformation of standard forms to simplified forms, to eliminate redundant operations in measurement and calculation.
2. Standardization of test variables wherever possible to eliminate redundant operations in measurement and calculation.
3. The use of non-linear representations.
4. The use of non-linear instrument scales to eliminate repetitive operations in calculation.

All of these techniques must be used within the limitations of a suitable experimental design, and with due consideration given to the hazards involved. Most common of these are the danger of extrapolation, and the familiar experience that "standard" methods, which serve a useful purpose in simplification, in time become "sacred", and can become impediments unless they are taken out occasionally for a critical airing. It is easy, for example, to lose sight of the fact that the defining relationship for modulus of rupture

$$\frac{3Ps}{2bd^2} = \text{constant} = \text{MOR (for constant board density)}$$

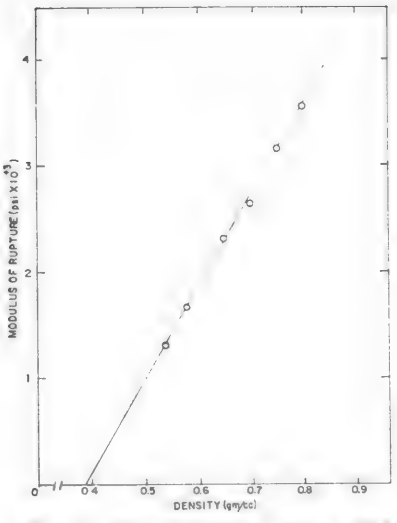
is not strictly applicable to particle board overall values of *s*, *b*, and *d*, as some simple experiments will show. It is useful under some conditions, in which it can be used to correct data for *minor* deviations of the dimension variables from the standard operating point. It is safer to work with empirically established relationships between the actual measured variables, which do not convey the illusion of generality that emanates from a theoretically derived form.

The techniques described in this paper are perfectly general in application, and are not restricted to the two types of measurement that have been discussed.

In the case of particle board and hardboard, the particular function P/w^2 has been found to be broadly but not universally, applicable as a means of correcting flexural strength test data for variation in board density. The transformation of this function, $\sqrt{P}/w$, offers even greater promise in the simplification of data processing, particularly for screenback hardboard.

From a statistical point of view, the value of the simplified relationships depends on a proportionality relationship between the simplified function and the formal expression. From an operational point of view, the use of proportional expressions is equivalent to multiplicative coding of the data. With this type of coding, the mean and the standard deviation of the transformed set of data are both proportional to the mean and standard deviation of the original set of data, and the coefficient of variation is the same for both sets. The development of simplified forms merely builds a multiplicative code into the data-handling system at the point where the data is being gathered.

The device by which the board thickness was eliminated from consideration appears to be particularly applicable to unsanded boards. These boards are sold on an area basis at a nominal thickness, and the end-use strength requirement does not take into account the thickness of the board. All boards should meet a minimum breaking load requirement, whether they are under or over the nominal thickness. The form $\sqrt{P}/w$, if it is applicable to the board in question, gives three things: the value of $\sqrt{P}$ is a direct measure of the board strength, the value of w is a direct measure of the material cost of the board per unit area, and the quotient of the two values is a measure of process control with respect to such things as resin efficiency, degree of cure of the resin binder, the effect of resin distribution, changes in the source or form of the basic raw material, and so forth. If for any reason it is desirable to express the strength values in units of MOR, the values of $\sqrt{P}$ may be transformed using the standard dimensions of the samples from which the $\sqrt{P}$ value was obtained, and using the *nominal* thickness value at which the board is sold.



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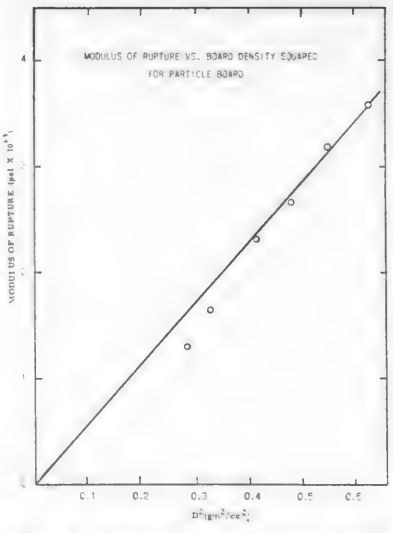

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			WW-22			
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Flexural strength data are shown in the simplified form P/w^2 (independent of density variation). Internal bond data are shown in the simplified form Bd/w (independent of density variation).

Summary and Conclusions

An attempt has been made to show the potential value of some simplified data-handling techniques in the analysis of physical test data. Application of these techniques has been illustrated for flexural strength testing in the case of particle board and hardboard, and the measurement of internal bond strength in particle board.

The four techniques that have been described are:

1. Algebraic transformation of standard forms to simplified forms, to eliminate redundant operations in measurement and calculation.
2. Standardization of test variables wherever possible to eliminate redundant operations in measurement and calculation.
3. The use of non-linear representations.
4. The use of non-linear instrument scales to eliminate repetitive operations in calculation.

All of these techniques must be used within the limitations of a suitable experimental design, and with due consideration given to the hazards involved. Most common of these are the danger of extrapolation, and the familiar experience that "standard" methods, which serve a useful purpose in simplification, in time become "sacred", and can become impediments unless they are taken out occasionally for a critical airing. It is easy, for example, to lose sight of the fact that the defining relationship for modulus of rupture

$$\frac{3Ps}{2bd^2} = \text{constant} = \text{MOR (for constant board density)}$$

is not strictly applicable to particle board overall values of *s*, *b*, and *d*, as some simple experiments will show. It is useful under some conditions, in which it can be used to correct data for *minor* deviations of the dimension variables from the standard operating point. It is safer to work with empirically established relationships between the actual measured variables, which do not convey the illusion of generality that emanates from a theoretically derived form.

The techniques described in this paper are perfectly general in application, and are not restricted to the two types of measurement that have been discussed.

In the case of particle board and hardboard, the particular function P/w^2 has been found to be broadly but not universally, applicable as a means of correcting flexural strength test data for variation in board density. The transformation of this function, $\sqrt{P}/w$, offers even greater promise in the simplification of data processing, particularly for screenback hardboard.

From a statistical point of view, the value of the simplified relationships depends on a proportionality relationship between the simplified function and the formal expression. From an operational point of view, the use of proportional expressions is equivalent to multiplicative coding of the data. With this type of coding, the mean and the standard deviation of the transformed set of data are both proportional to the mean and standard deviation of the original set of data, and the coefficient of variation is the same for both sets. The development of simplified forms merely builds a multiplicative code into the data-handling system at the point where the data is being gathered.

The device by which the board thickness was eliminated from consideration appears to be particularly applicable to unsanded boards. These boards are sold on an area basis at a nominal thickness, and the end-use strength requirement does not take into account the thickness of the board. All boards should meet a minimum breaking load requirement, whether they are under or over the nominal thickness. The form $\sqrt{P}/w$, if it is applicable to the board in question, gives three things: the value of $\sqrt{P}$ is a direct measure of the board strength, the value of w is a direct measure of the material cost of the board per unit area, and the quotient of the two values is a measure of process control with respect to such things as resin efficiency, degree of cure of the resin binder, the effect of resin distribution, changes in the source or form of the basic raw material, and so forth. If for any reason it is desirable to express the strength values in units of MOR, the values of $\sqrt{P}$ may be transformed using the standard dimensions of the samples from which the $\sqrt{P}$ value was obtained, and using the *nominal* thickness value at which the board is sold.

Time-Dependent Strain Behavior of Wood

IN TENSION PARALLEL TO THE GRAIN[1,2]

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WOOD, when tested by standard methods (2)[3], exhibits mechanical behavior which approaches that defined by Hooke's Law. Conventional elastic theory, however, does not lend itself to a complete description of the mechanical behavior of wood because it does not account for the dimension of time.

Numerous investigations (3, 4, 7, 9, 11, 12, 20–24, 31–33, 35–38, 42, 44) have shown that wood creeps at stress levels as low as 10 percent of the short-term strength, levels that are far below the proportional limit. Other studies (7, 17, 29, 37, 38, 42, 43) concerned with long-term strength indicate that loads from 60 to 70 percent of the short-term maximum load will cause failure in one to three years.

The dependence of strength on time under load is illustrated in a different manner by studies concerned with the effects of rate of loading (6,26,29,43). These studies indicate that modulus of rupture, maximum crushing strength, and stresses at the proportional limit increase with an increase in the rate of loading. The traditional interpretation of proportional limit is that it marks the threshold of plastic flow or irrecoverable strain. Since stress and strain at the proportional limit are variable quantities, it is difficult to apply this interpretation directly to the case of wood.

Another point of view is expressed by Ivanov (15) who contends that there is no such thing as a proportional limit with wood, and that the stress-strain relation is curvilinear from the very beginning of loading. Ivanov characteristics the region of the stress-strain relation below a certain limit, which he calls the lower limit of plastic flow, as one in which the change in strain (with respect to a change in stress) is proportional to the level of stress. According to Hooke's Law, this rate is constant. Ivanov's initial thesis was that his lower limit of plastic flow corresponded to the safe long-term strength. It has been reported recently, however, that this limit also varies with the rate of loading, and thus is not readily identified with long-term strength (16,39).

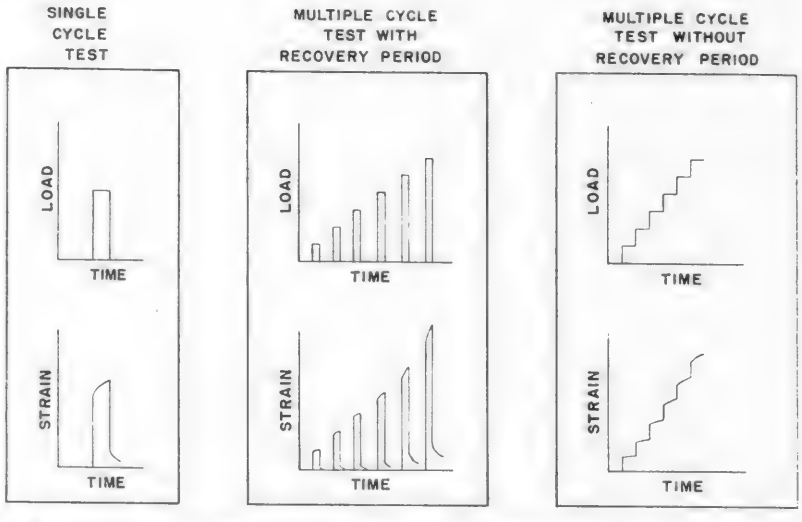

Fig. 1.—Schematic illustration of different loading schedules used in this investigation.

The foregoing discussion directs attention to the need for modifying and correlating existing concepts that deal with the nature of the behavior of wood under load. Analyses directed toward this end must take into account the effects of the time factor.

The purpose of the study was to establish the characteristic behavior of wood under load in tension parallel to the grain through investigation of the short-time creep properties of a number of domestic and tropical species. Specific objectives were to determine: (a) the nature of the creep rate-stress level relationship; (b) the stress and strain levels at which set begins; and (c) the extent to which species differ in their response to a sustained load.

Preliminary results of this study were reported and discussed in two previous papers (18,19). This report summarizes the results of the entire study.

Test Procedure

Creep behavior at room temperature and 12 percent moisture content was investigated in this study by means of the type B tension specimen described in ASTM D805–52. Specimens were conditioned and stored over a saturated sodium nitrite solution at laboratory temperatures prior to test. All tests were conducted at a temperaure within the range of 75° to 86°F.

Loads were applied by means of Templin self-aligning and self-tightening grips in a Baldwin–Southwark hydraulic testing machine. Strains were measured to the nearest micro-inch with SR–4, A–5 papermounted electrical resistance strain gages and a Baldwin strain analyzer.

Matched specimens were tested in two groups. The specimens in one group served as the compensating gages for specimens in the other group being tested. During test the specimen with the compensating gage was held firmly in a special jig designed for this purpose.

Three different types of loading schedules were employed in this investigation: a single-cycle test and a multiple-cycle test with and without a recovery period.

Single-Cycle 30-Minute Creep Test: The creep behavior of basswood, red oak, redwood, Douglas-fir, cedro branco (*Cedrela huberi*), determa (*Ocotea rubra*), angelique (*Dicorynia paraensis*), timbauba (*Enterolobium Schomburgkii*), kaneelhart (*Licaria cayennensis*), manwood

[1] A contributed paper, received Oct. 1960, condensed from a thesis submitted for the D. For. degree at Yale Univ. Revised for publication Jan. 30, 1961.

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[2] This research is part of a comprehensive study being conducted at the Yale School of Forestry in cooperation with the Office of Naval Research, Dept. of Navy, under Contract Nonr 609 (13), Proj. NR 330–001, Properties of Tropical Woods.

[3] Numbers in parentheses refer to the Literature Cited at the end of this paper.

- **Creep is proportional to log of time for only first 30 or 40 minutes.**
- **Creep occurs in all species at stress levels 15% of short-time strength or less.**
- **Set begins to occur at about the same initial extension region for all species.**
- **Creep-initial strain and creep-stress level show a two-stage relationship.**
- **Sp. Gr. and max. tensile strain account for much difference in creep behavior below threshold of set.**

Minquartia guianensis), and cupiuba *Goupia glabra*) was investigated to determine the general relationship between the magnitude of the creep response and level of stress, and also the extent to which species differ in their response to a sustained load. These 11 species provided a range of wood specific gravity from 0.32 to 1.04. Each species was represented by specimens from different boards, the specimens from a particular board being designated as a test series.

Measurements of creep were taken over a 30-minute period for stress levels from 6 to 86 percent of ultimate tensile strength. After a 14-minute warm-up period for both the active and compensating strain gages, each test specimen was loaded to the desired load level in one minute, and the load maintained for a 30-minute period. After the completion of all sustained-load tests for a particular species, each specimen was tested to failure at a machine speed of 0.035 inch per minute.

Multiple-Cycle Creep Tests: The exact manner in which creep and stress level are related cannot be established without considering the stress, or initial strain, at which set first begins to occur. If such a threshold of set or yield point exists, it is conceivable that the relationship between creep and stress level changes as the threshold is exceeded.

To determine the approximate threshold of permanent set, each of a number of specimens was tested at successively higher stress levels until significant set occurred, as shown by an increase in zero-load strain.[4] Loads were applied in one minute, maintained for 30 minutes, and then removed. After each loading cycle, the specimens were stored over a saturated sodium nitrite solution at laboratory temperatures. Specimens were reloaded when recovery was virtually complete. Zero-load strains were measured with the specimens firmly held in the special jig and after a five-minute gage warm-up period.

Another form of the step-wise test was used to estimate the effect of creep on the stress-strain relationship obtained from the static test to failure. In this case, the loads were applied in ½ minute and maintained for only 10 minutes. At the end of each sustained-load period, the specimens were immediately loaded to the next higher load station.

The different types of loading schedules employed in this investigation are illutsated in Fig. 1.

Results and Discussion

Creep-Time Relationship: The creep that occurred during the single-cycle 30-minute sustained-load tests and the 30-minute and 10-minute multiple-cycle tests was found to be proportional to the logarithm of time. Regressions were therefore fitted by the method of least squares to the creep—logarithm of time data for all specimens that were tested according to these three loading schedules.

The general equations obtained were of the form

$$\epsilon = \epsilon_o + b \cdot \log(t+1) \quad --1)$$

$$\frac{d\nu}{dt} = \frac{b}{t+1} \cdot \frac{1}{1n\ 10} \quad --2)$$

where: t = time under sustained load, minutes

ϵ = total strain, micro-inches per inch

ϵ_o = initial strain, micro-inches per inch

and: b = constant

The creep rate at any time within the experimental time-scale, and the creep occurring during the sustained-load period can be calculated from equations 1) and 2) if the constant b is known. This constant, which defines the magnitude of the creep response, has been designated as the "creep-index".

It can be seen from equations 1) and 2) that the relationship between creep index and initial strain will be of the same type as the relationship between creep and initial strain or between creep rate and initial strain.

It should be mentioned that a number of exploratory 12-hour creep tests indicated that, after the first 30 to 40 minutes, creep tends to increase more than linearly with increase in logarithmic time. This type of behavior is typical of the behavior of high polymers in general (1,25,30,31,40).

Multiple-Cycle Creep Tests with Recovery Period Between Cycles: Nineteen specimens, representing eight species, were tested in stepwise fashion at successively higher stress levels to determine the approximate stress and strain levels at which set is initiated. Set measurements were based on the increase in zero-load strain that occurred at each load level. Zero strains were measured after recovery was virtually complete. Set was assumed to have occured when the zero-load strain was ten or more microinches per inch greater than the base strain and when this set progressively increased with subsequent testing.

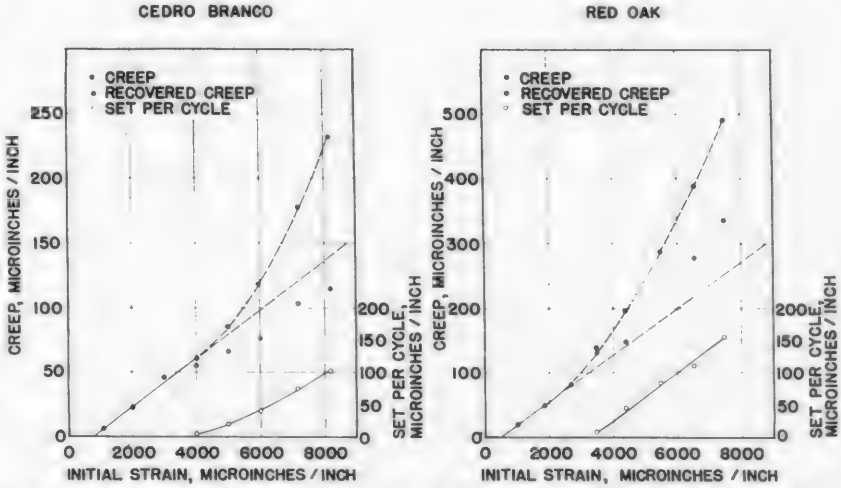

Fig. 2.—The creep—initial strain and set per cycle—initial strain relationships for cedro branco and red oak specimens tested in step-wise fashion at successively higher stress levels with a recovery period between cycles. Values shown for each species are averages based on the results of three specimens. Creep values represent the creep occuring in a 30-minute sustained-load period.

[4] Zero-load strain refers to the strain indicator reading when the active and compensating gages are under no load.

Typical creep and recovery data for this series of tests are summarized in Table 1. The relationship of creep and set with initial strain for red oak and cedro branco are illustrated in Fig. 2.

It can be seen from Table 1 and Fig. 2 that creep is approximately proportional to level of strain up to the threshold of set, but in general tends to increase more than linearly with increasing strain after set has begun. Immediate or initial strain also appears to be fully recoverable.

The maximum initial strain at which no set was observed and the minimum initial strain at which set was first observed are given in Table 2 for the 19 specimens. It can be seen from the table that these maximum and minimum initial strains are of approximately the same magnitude for the eight species investigated. Considering the fact that all species have the same type of cell wall and molecular structure, such behavior is not unreasonable. Differences do exist between species, however, with regard to orientation of the chain molecules and crystallinity of the micellar system, lignin and extractive content, and in size and type of anatomical elements present. Therefore, the initial strain which characterizes the threshold of set is, in all likelihood, not the same for all species, but probably varies within certain defined limits. With a more accurate method of measuring set than that used in this study, and with a larger number of tests, these differences might be revealed.

The two average strain values, the maximum initial strain at which no set was observed and the minimum initial strain at which set was first observed, would seem to define the region of initial extension in which set is initiated. The midpoint between these two values was selected as a conservative average estimate of the threshold of set

Table 1.—SUMMARIZED CREEP AND RECOVERY DATA FOR CEDRO BRANCO, RED OAK, ANGELIQUE, TIMBAUBA, BASSWOOD, REDWOOD, AND DOUGLAS-FIR BASED ON THE RESULTS OF SPECIMENS TESTED IN STEPWISE FASHION AT SUCCESSIVELY HIGHER STRESS LEVELS WITH A RECOVERY PERIOD BETWEEN CYCLES

Species	Number of specimens on which values are based	Cycle number	Initial strain	Creep index	Creep 0–30 min.	Set[1] per cycle
			microinches per inch		microinches per inch	
Cedro branco	3	1	1070	3.78	6	0
		2	2020	15.29	23	0
		3	3000	30.64	46	0
		4	4010	40.06	60	5
		5	4980	57.23	85	19
		6	5950	78.73	117	41
		7	7220	119.37	178	75
		8	8200	155.25	232	117
Red oak	3	1	1020	14.33	21	0
		2	1850	32.74	49	0
		3	2680	55.85	83	0
		4	3480	93.03	139	7
		5	4420	130.22	194	46
		6	5500	193.25	288	84
		7	6550	261.07	389	111
		8	7480	329.67	492	155
Angelique	2	1	910	0.36	1	0
		2	1750	8.82	13	0
		3	2660	18.62	28	0
		4	3520	27.23	41	0
		5	4590	34.50	51	20
		6	5490	51.74	77	30
		7	6320	76.79	115	55
		8[2]	7210	143.12	213	62
Timbauba	2	1	1510	5.43	8	0
		2	2490	20.92	31	0
		3	3590	35.19	52	0
		4	4790	57.79	86	13
		5	5780	74.24	111	24
		6	6820	99.80	149	60
Basswood	2	1	1130	19.08	28	0
		2	2200	49.23	73	0
		3	3360	85.46	127	0
		4	4390	150.92	225	24
		5	5480	194.03	289	77
		6	6660	308.08	459	146
Kaneelhart	2	1	760	—3.16	—5	0
		2	1440	1.80	3	0
		3	2060	5.72	9	0
		4	2900	11.25	17	0
		5	3640	14.80	22	0
		6	4340	23.78	35	24
		7	5040	28.36	42	38
		8	5720	29.26	44	51
Redwood	1	1	1320	1.30	2	0
		2	1850	14.64	22	0
		3	2440	35.91	54	0
		4	2380	27.91	42	0
		5	2990	43.97	66	0
		6	3500	48.32	72	0
		7	4170	53.29	80	0
		8	4730	62.89	94	0
Douglas-fir	1	1	1500	8.35	12	0
		2	1490	12.66	19	0
		3	2220	21.63	32	0
		4	2920	28.10	42	0
		5	3630	33.04	49	0
		6	4540	59.70	89	0
		7	5240	61.16	91	24

[1]Set after recovery virtually complete.
[2]Values for eighth cycle based on one specimen.

Table 2.—ESTIMATES OF THE INITIAL STRAIN AT WHICH SET BEGINS

Series	Specimen	Estimated thresholds of set: Maximum initial strain at which no set observed	Estimated thresholds of set: Minimum initial strain at which set first observed
		microinches per inch	microinches per inch
Cedro branco	S1	3110	4110
	S2	4720	5660
	S3	4090	5110
	S4	2390	3240
Red oak	S5	3510	4370
	S6	2780	3760
	S7	3180	4200
	S8	2310	3300
Angelique	S9	3560	4680
	S10	3480	4510
Timbauba	S11	3150	4520
	S12	4040	5060
Basswood	S13	3360	4490
	S14	----	4300
Kaneelhart	S15	3560	4270
	S16	3710	4420
Redwood	S17	4730	----
	S18	3640	4230
Douglas-fir	S19	4540	5240
Number		18	18
Average		3550	4420
Final estimate		3980	

Table 3.—SUMMARIZED CREEP DATA FOR CEDRO BRANCO AND RED OAK TESTED IN STEPWISE FASHION WITH NO RECOVERY PERIOD BETWEEN CYCLES

Species	Number of specimens on which values are based	Cycle number	Sustained stress[1]	Initial strain	Creep index	Maximum strain
			psi	microinches per inch		microinches per inch
Cedro branco[2]	3	1	1,760	1,100	3.50	
		2	3,520	2,170	8.85	
		3	5,280	3,260	14.70	
		4	7,040	4,350	28.33	
		5	8,800	5,450	49.36	
		6	10,570	6,580	59.00	----
Cedro branco[3]	3	1	1,500	970	4.90	
		2	3,000	1,900	9.63	
		3	4,500	2,830	18.23	
		4	6,000	3,790	25.98	
		5	7,510	4,750	35.35	
		6	9,010	5,710	50.73	
		7	10,510	6,680	65.71	
		8	12,010	7,670	81.72	
		9	13,510	8,710	99.87	
		10	15,010	9,690	125.27	
		11	16,510	10,730	145.30	11,730
Red oak[3]	3	3	1,810	780	0.57	
		2	3,010	1,350	8.95	
		3	4,810	2,210	25.22	
		4	6,610	3,090	44.04	
		5	8,420	3,970	75.54	
		8	10,220	4,880	106.46	
		7	12,020	5,800	137.43	
		8	13,830	6,740	174.16	
		9	15,630	7,720	209.51	
		10	17,430	8,710	254.74	9,690

[1]The sustained load period was of 10-minute duration. A loading time of ½-minute was used between cycles.
[2]Specimens providing data for this group were matched with the specimens providing the creep-recovery data for this species in Table 1.
[3]Specimens tested until failure occurred.

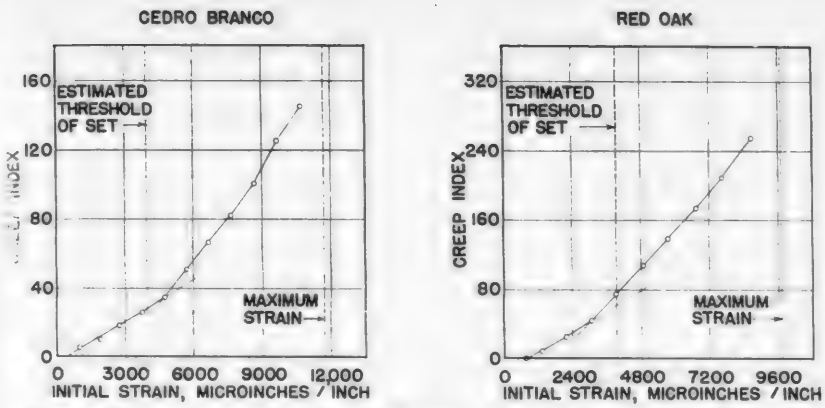

Fig. 3.—The creep index—initial strain relationships for cedro branco and red oak specimens tested in step-wise fashion at successively higher stress levels with no recovery period between cycles. Values shown for each species are averages based on the results of three specimens. Creep index refers to the slope of the creep—logarithmic time regression.

wood in tension parallel to the grain. This estimate was 3980 microinches per inch, an initial extension of approximately 0.40 percent. Minami (32) conducted step-wise loading tests on two specimens (Sitka spruce and hinoki) and found significant set first occurred at initial strains of approximately the same magnitude.

The stress level at which set first begins to occur appears to vary considerably between species. The average maximum stress level at which no set was observed was approximately 42 percent, with individual specimen values ranging from 21 to 80 percent.

Multiple-Cycle Creep Tests with No Recovery Period Between Cycles: The results of the multiple-cycle creep and recovery tests indicated that creep increases more than proportionally with increasing initial strain once set begins to occur. This suggests that some form of yielding begins as the threshold of set is exceeded.

To verify this point, three cedro branco specimens (which were taken from the same board as were those specimens providing the creep and recovery data for this species in Table 1) were tested at six successively higher levels of stress without permitting the specimens to recover between cycles. This type of multiple-cycle creep test reduces the creep that occurs at any given station and thus tends to emphasize the effect of internal structural changes that occur as the specimen is loaded from one station to another. The average values for sustained stress, initial strain, and creep index at each load level for this series of tests are given in Table 3.

By comparing the average creep index and initial strain values given in Table 3 for these specimens with the average set per cycle and initial strain values given in Table 1 for the matched specimens (which were also tested in step-wise fashion but with a recovery period between cycles), it can be seen that the initial strain region characterizing the threshold of set also appears to delineate a region where yielding begins.

Further substantiation of the yield-point concept was obtained from the results of three additional cedro branco specimens and three red oak specimens that were tested at successively higher stress levels until failure occurred. The results of these tests are summarized for each species in Table 3 and illustrated in Fig. 3.

The estimated threshold of set shown in Fig. 3 is the average threshold of 0.40 percent extension estimated from the data for eight species in the multiple-cycle creep and recovery tests. In addition to illustrating the apparent yielding that occurs when set begins, Fig. 3 also indicates that there is no readily discernible threshold of failure other than the threshold of set.

No definite statements can be made regarding the question of whether the threshold of set is also a threshold of failure. On the basis of available information, however, it seems unlikely. Applying to wood the results of investigations (28, 34, 40) concerned with the mechanical behavior of cellulose fibers, it seems likely that a portion of the set that occurs at initial strains greater than the threshold strain may be recovered by heating and soaking treatments. This suggests that the development of set is not necessarily accompanied by structural weakening,

Table 4.—MAXIMUM STRAIN AND INITIAL STRAIN REGRESSION DATA FOR 11 DOMESTIC AND TROPICAL SPECIES

Species	Specific gravity (O.D. vol.)	Average maximum strain microinches per inch	Regressions[1]	Initial strain range of fitted experimental data microinches per inch	Number of tests
Redwood	0.32	6,420	Linear: $CI = -10.9738 + 0.02006\ \epsilon_0$	1,060– 4,800	11
Redwood	0.37	5,450	Linear: $CI = -5.7882 + 0.13756\ \epsilon_0$	1,060– 4,420	14
Basswood	0.40	8,720	Linear: $CI = -13.8391 + 0.03158\ \epsilon_0$	520– 4,410	23
			Exponential: $CI = e^{(3.6050 + 0.0003011\ \epsilon_0)}$	3,460–10,320	6
Douglas-fir	0.45	8,290	Linear: $CI = -1.2621 + 0.01209\ \epsilon_0$	780– 4,490	16
			Exponential: $CI = e^{(1.6551 + 0.0005311\ \epsilon_0)}$	3,920– 6,740	8
Cedro branco	0.46	10,060	Linear: $CI = -8.7338 + 0.01620\ \epsilon_0$	920– 3,640	11
			Exponential: $CI = e^{(2.8422 + 0.0002942\ \epsilon_0)}$	3,530– 9,220	18
Determa	0.52	9,080	Linear: $CI = -17.5652 + 0.02180\ \epsilon_0$	770– 4,070	21
			Exponential: $CI = e^{(1.9590 + 0.0005537\ \epsilon_0)}$	3,640– 6,430	15
Douglas-fir	0.55	7,420	Linear: $CI = -5.6248 + 0.01049\ \epsilon_0$	1,120– 3,700	22
Red oak	0.64	12,630	Linear: $CI = -22.3596 + 0.03462\ \epsilon_0$	1,140– 4,410	13
			Exponential: $CI = e^{(3.5599 + 0.0002988\ \epsilon_0)}$	3,620– 9,800	17
Cupiuba	0.76	12,630	Linear: $CI = -3.0663 + 0.00857\ \epsilon_0$	510– 3,060	21
Angelique	0.78	9,070	Linear: $CI = -11.1616 + 0.01245\ \epsilon_0$	750– 3,890	11
			Exponential: $CI = e^{(2.2489 + 0.0003724\ \epsilon_0)}$	3,890– 7,430	13
Monwood	0.89	10,720	Linear: $CI = -21.2323 + 0.01822\ \epsilon_0$	940– 3,980	7
			Exponential: $CI = e^{(2.8324 + 0.0002992\ \epsilon_0)}$	3,980– 8,100	11
Tingauba	0.94	10,420	Linear: $CI = -13.0730 + 0.01351\ \epsilon_0$	980– 3,580	13
			Exponential: $CI = e^{(2.1665 + 0.0004042\ \epsilon_0)}$	3,540– 7,980	17
Kaneelhart	1.04	7,470	Linear: $CI = -6.0450 + 0.00701\ \epsilon_0$	480– 4,290	21
			Exponential: $CI = e^{(0.1146 + 0.0007300\ \epsilon_0)}$	3,810– 5,570	11

[1] CI = Creep index.
ϵ_0 = Initial strain, microinches per inch.

and further, that set is not entirely the result of viscous flow. Another point for consideration is the possibility that molecular crystallization may occur at initial extensions greater than the threshold of set. Such behavior would tend to reduce the creep rate and facilitate the attainment of equilibrium.

Single-Cycle Creep Tests: The creep behavior of 11 species was investigated by means of the single-cycle loading procedure.

The results of the multiple-cycle creep tests indicated that the most accurate description of the creep—initial strain and creep—stress level relations was a two-stage relationship consisting of a linear regression up to the threshold of set and a curvilinear regression thereafter. The results of the single-cycle creep tests substantiated this concept of a two-stage relationship.

Consequently, linear regressions of the form

$$CI = a + bX$$

and exponential regressions of the form

$$CI = e^{(c + dX)}$$

where: CI = creep index

X = initial strain, microinches per inch or stress level, percentage of ultimate strength

a, b, c, d = constants

and: e = base of natural logarithms

were fitted to the creep-index initial strain and creep index—stress level data of the 11 species. The regression equations, the operative range of each equation, and the number of experimental values considered in fitting each equation are given in Table 4 and 5, Average values of specific gravity, maximum strain, and ultimate tensile strength for each species are also given in these tables.

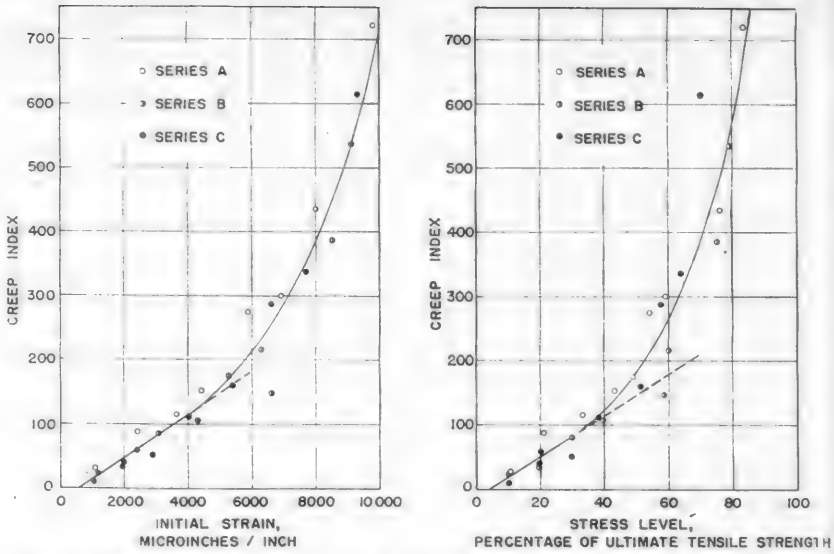

Fig. 4—The creep index—initial strain and creep index—stress level relationship for red oak. Creep index values refer to the slope of the creep—log time regression for each specimen. Stress levels are expressed as percentages of the average ultimate tensile strength of each series.

It was evident from the test results for Douglas-fir and redwood that each of these species was represented by two distinct groups of specimens, which differed in both creep and specific gravity. Therefore, the specimens of each of these species were divided into two groups to facilitate the analysis.

As reported in the previous section, the average maximum initial extension at which no set was observed in specimens tested in stepwise fashion at successively higher levels of stress was approximately 0.35 percent. This value was used to establish a lower boundary for the exponential regressions. The creep index—initial strain values and the creep index—stress level values of specimens tested at initial extensions greater than 0.35 percent were considered in the fitting of the exponential regressions. Experimental values at lower levels of strain were described with the linear regression. Some test values at initial extensions between 0.35 and 0.45 percent, which were included in the fitting of the exponential regression, were also considered in the fitting of the linear regressions. This somewhat arbitrary procedure of con-

Table 5.—ULTIMATE TENSILE STRENGTH AND STRESS LEVEL REGRESSION DATA FOR 11 DOMESTIC AND TROPICAL SPECIES

Species	Specific gravity (O.D. vol.)	Average ultimate tensile strength psi	Regression[1]		Stress level range of fitted experimental data percent	Number of tests
Redwood	0.32	6,980	Linear:	$CI = -4.1902 + 1.1449\ \sigma_L$	15–84	11
Redwood	0.37	7,350	Linear:	$CI = -3.9215 + 0.7130\ \sigma_L$	18–80	14
Basswood	0.40	12,120	Linear:	$CI = -12.4279 + 2.5486\ \sigma_L$	6–46	22
			Exponential:	$CI = e^{(2.6396 + 0.04514\ \sigma_L)}$	46–90	6
Douglas-fir	0.45	14,690	Linear:[2]	$CI = +0.8942\ \sigma_L$	10–59	16
			Exponential:	$CI = e^{(0.1912 + 0.06584\ \sigma_L)}$	49–72	8
Cedro branco	0.46	15,980	Linear:	$CI = -4.3291 + 1.3080\ \sigma_L$	10–41	12
			Exponential:	$CI = e^{(2.5444 + 0.03347\ \sigma_L)}$	41–86	18
Determa	0.52	10,330	Linear:	$CI = -13.8075 + 1.6309\ \sigma_L$	10–55	20
			Exponential:	$CI = e^{(1.7785 + 0.04626\ \sigma_L)}$	44–80	15
Douglas-fir	0.55	19,980	Linear:	$CI = -5.2888 + 0.7434\ \sigma_L$	14–56	22
Red Oak	0.64	19,780	Linear:	$CI = -12.4537 + 3.1962\ \sigma_L$	10–40	12
			Exponential:	$CI = e^{(3.3189 + 0.03789\ \sigma_L)}$	33–84	17
Cupiuba	0.76	14,060	Linear:	$CI = -3.3886 + 0.5988\ \sigma_L$	8–45	17
Angelique	0.78	25,820	Linear:	$CI = -11.0463 + 1.0566\ \sigma_L$	10–48	11
			Exponential:	$CI = e^{(2.2132 + 0.03252\ \sigma_L)}$	41–83	13
Manwood	0.89	29,090	Linear:	$CI = -19.0587 + 1.8198\ \sigma_L$	9–40	7
			Exponential:	$CI = e^{(2.6653 + 0.03319\ \sigma_L)}$	40–79	11
Timbauba	0.94	34,960	Linear:	$CI = -10.9968 + 1.2479\ \sigma_L$	10–36	13
			Exponential:	$CI = e^{(2.1601 + 0.04182\ \sigma_L)}$	36–72	17
Kaneelhart	1.04	32,190	Linear:	$CI = -7.8284 + 0.6188\ \sigma_L$	7–58	22
			Exponential:	$CI = e^{(1.6895 + 0.02909\ \sigma_L)}$	47–76	11

[1] CI = Creep index.
σ_L = Stress level, percentage of ultimate tensile strength.
[2] Regression forced through origin. Calculated intercept of +2.6237 indicates creep at zero load.

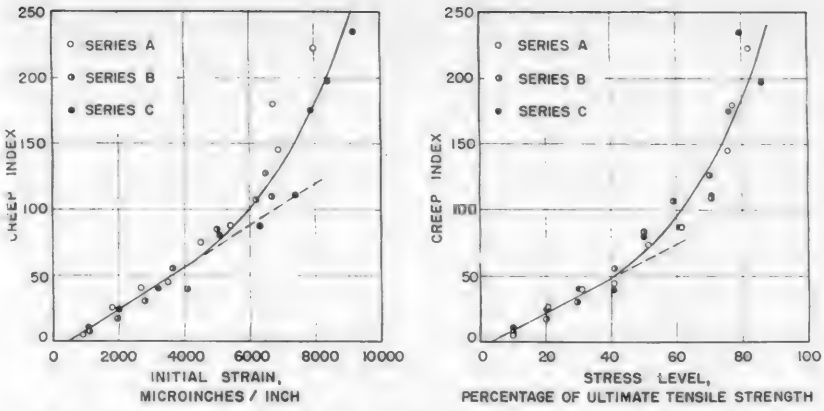

Fig. 5.—The creep index—initial strain and creep index—stress level relationship for cedro branco. Creep index values refer to the slope of the creep—logarithmic time regression for each specimen. Stress levels are expressed as percentages of the average ultimate tensile strength of each series.

idering some values twice was employed in order to obtain a reasonable description of the experimental data in the region of the threshold of set. The two regressions were not forced to intersect nor to be tangent because sufficient data were not available to define either a most probable average threshold of set nor the exact limits of the threshold region for each species. By comparing the range of threshold values for individual specimens in Table 2 with the initial strain range of the fitted experimental data in Table 4, it can be seen that the region in which the regressions overlap is reasonably small.

The creep index—initial strain and the creep index—stress level regressions for red oak, cedro branco, and Douglas-fir (specific gravity 0.45) are shown with the experimental values in Fig. 4–6.

The creep behavior of the 11 species investigated is compared on an initial strain basis in Fig. 7 and on a stress-level basis in Fig. 8. These figures indicate that there are substantial differences between species with regard to the magnitude of the creep response.

The linear and exponential regressions used to describe the creep—initial strain and creep—stress level relationships fit the experimental data reasonably well. However, the exponential regressions for many of the species were either not tangent or failed to intersect the linear regressions in the region of the threshold of set. It seems only reasonable to expect that, if all sources of variation between specimens could be removed and if specimens were tested at sufficiently close load levels, and linear and curvilinear regressions should meet and be tangent at the threshold of set. The possibility exists that the creep of some or all species may not increase exponentially above the threshold of set but may increase in a different manner, for example hyperbolically. If the quantity —order distribution of the cellulose chains were, for a species, relatively narrow and unimodal, the hyperbolic equation might provide a more accurate description than the exponential equation. The results of this study indicate only that, for those species in which a substantial number of specimens were tested at levels above the threshold, the

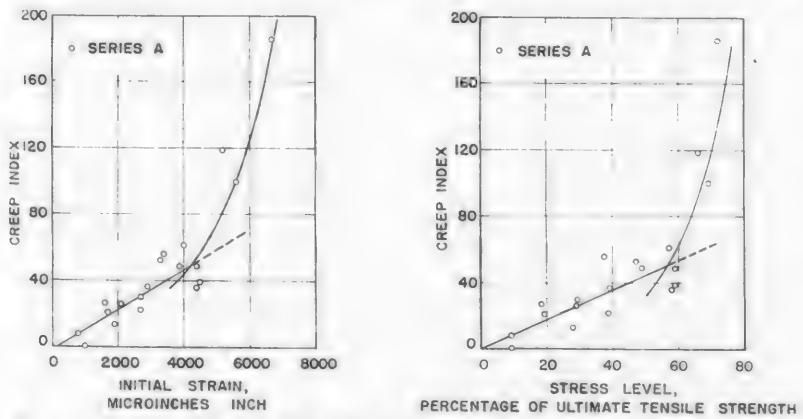

Fig. 6.—The creep index—initial strain and creep index—stress level relationship for Douglas-fir, specific gravity 0.45. Creep index values refer to the slope of the creep—logarithmic time regression for each specimen. Stress levels are expressed as percentages of the average ultimate tensile strength of each series.

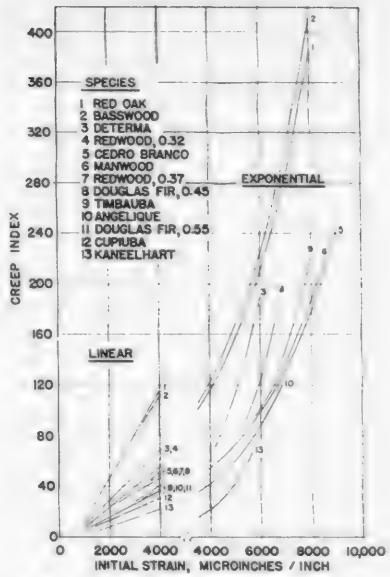

Fig. 7.—Comparison of the linear and exponential creep index—initial strain regressions of the eleven species investigated.

exponential equation provided a reasonable description, and in a number of cases, came very close to fulfilling the tangency requirement.

With regard to the two-stage relationship between creep and stress level, it is interesting to note that Grossman and Kingston (9) found that creep of a number of hoop pine specimens in tension parallel to the grain increased more than linearly with increasing stress, and that the greater part of the non-linear increase was due to irrecoverable strain. Conversely, tests at the Forest Products Laboratory (42) indicated that creep of Douglas-fir and white oak in tension was approximately proportional to stress. The results of this study indicate that creep and stress are proportional below the threshold of set only.

The average specific gravity, ultimate tensile strength, modulus of elasticity[5], maximum strain, and ratio of tensile strength to modulus of elasticity are given for each of the 11 species in Table 6. Regression equations of tensile strength, modulus of elasticity, and maximum strain with specific gravity, and their respective coefficients of determination, are given in Table 7. As expected, a high degree of correlation was found between strength and specific gravity ($r^2 = 80$ percent) and between stiffness and specific gravity ($r^2 = 84$ percent). The 3 percent r^2 value for the maximum strain—specific gravity regression indicates that these properties are relatively independent of each other.

[5] Modulus of elasticity values for each species were calculated from the creep test data of each specimen by dividing the sustained stress (applied in one minute) by the initial strain. Only those specimens tested at initial strains less than 6000 microinches were considered in order to minimize the effect of creep.

Table 6.—AVERAGE TENSILE STRENGTH PROPERTIES AND ACTUAL AND ESTIMATED MAXIMUM STRAINS FOR SELECTED DOMESTIC AND TROPICAL SPECIES

Species	Specific gravity (O.D. vol.)	Ultimate tensile strength psi	Modulus of elasticity 10^6 psi	Maximum strain microinches per inch	Ultimate tensile strength ÷ modulus of elasticity
Redwood	0.35	7,180	1.22	5,840	5,890
Basswood	0.40	12,120	1.45	8,720	8,360
Cedro branco	0.46	15,980	1.66	10,060	9,630
Douglas-fir	0.51	18,070	2.48	7,730	7,290
Determa[1]	0.52	10,330	1.31	9,080	7,890
Red oak	0.64	19,780	1.86	12,630	10,630
Cupiuba[1]	0.76	14,060	2.34	6,040	6,010
Angelique	0.78	25,820	3.02	9,070	8,550
Manwood	0.89	29,090	2.84	10,720	10,240
Timbauba	0.94	34,960	3.46	10,420	10,100
Kaneelhart	1.04	32,190	4.38	7,470	7,350

[1]Species with naturally steep interlocked grain.

Table 8.—RELATIONSHIP BETWEEN WEIGHTED CREEP INDEX AND MAXIMUM STRAIN AT VARIOUS INITIAL EXTENSIONS

Initial extension	Number of species[1]	Equation[2]	r^2 percent
2000 microinches per inch	13	$\log(CI \times G) = 0.5576 + 0.00006022\ \epsilon_m$	58.7
3000 " " "	13	$\log(CI \times G) = 0.7147 + 0.00007053\ \epsilon_m$	70.4
4000 " " "	12	$\log(CI \times G) = 0.7853 + 0.00007988\ \epsilon_m$	74.3
5000 " " "	9	$\log(CI \times G) = 1.0920 + 0.00006682\ \epsilon_m$	45.3
6000 " " "	8	$\log(CI \times G) = 1.3245 + 0.00005928\ \epsilon_m$	30.9
Percentage strain level[3]:			
20 percent	13	$\log(CI \times G) = 0.2020 + 0.0001353\ \epsilon_m$	
30 "	13	$\log(CI \times G) = 0.0668 + 0.0001345\ \epsilon_m$	
40 "	13	$\log(CI \times G) = 0.1988 + 0.0001388\ \epsilon_m$	
50 "	13	$\log(CI \times G) = 0.2618 + 0.0001474\ \epsilon_m$	
60 "	11	$\log(CI \times G) = 0.3059 + 0.0001591\ \epsilon_m$	
70 "	11	$\log(CI \times G) = 0.3793 + 0.0001679\ \epsilon_m$	

[1]Considering each of the tow Douglas-fir and redwood groups as equivalent to a species.
[2]CI = Creep index associated with the particular initial extensions in column one.
G = Specific gravity, O.D. volume basis.
ϵ_m = Maximum strain, microinches per inch.
[3]Strain level expressed as a percentage of the maximum strain.

A coefficient of determination of 94 percent was obtained by equating maximum strain with the ratio of strength to stiffness. Maximum strain is closely approximated by this ratio because in short periods of time, creep is quite small relative to total extension.

In attempting to account for differences in the magnitude of the creep response of different species, it was found that, when creep index (at a given initial extension) was multiplied by specific gravity, a satisfactory exponential relationship was obtained with maximum strain. Relating the logarithm of creep index (at 3000 microinches per inch initial extension) times specific gravity to maximum strain gave a coefficient of determination of 70 percent. This initial extension is approximately the mean of all the experimental data.

It is evident from Fig. 7, however, that the 70 percent coefficient of determination value does not apply at the extremes of the data. At the lower extreme, the differences between species with regard to the magnitude of the creep response are less than those that exist at initial strains in the region of the threshold of set. It also can be seen from Fig. 7 that the relative order or position of some species tends to change (exponential regressions tend to cross) as the threshold of set is exceeded. Any transformation that effectively removes differences between species below the threshold of set cannot have the same effectiveness at higher initial strains if the relative positions of the species change as set begins to occur.

Table 7.—RELATIONSHIPS BETWEEN ULTIMATE STRENGTH, STIFFNESS, MAXIMUM STRAIN, AND SPECIFIC GRAVITY

Equations[1]	r^2 percent
$\sigma_m = -3,688 + 35,685\ G$	80.50
$E = -0.211 + 3.903\ G$	83.71
$\epsilon_m = 7,828 + 1,601\ G$	3.34
$\epsilon_m' = -1,167 + 1,2031\ \sigma_m/E$	94.43

[1]σm Ultimate strength, psi.
E = Modulus of elasticity, 10^6 psi.
ϵm = Maximum strain, microinches per inch.
G = Specific gravity, O.D. volume basis.

Equations that describe the relationship between the logarithm of creep index times specific gravity and maximum strain for initial strains of 2000, 3000, 4000, 5000, and 6000 microinches per inch, and their respective coefficients of determination, are given in Table 8. These equations were determined by means of creep index values calculated from the regressions in Table 4 (creep indices at the two largest initial strains were calculated from the exponential regressions).

As shown in Table 8, the coefficient of determination increased from 59 percent at an initial extension of 2000 microinches per inch to 74 percent at an extension of 4000 microinches per inch, and then decreased to 31 percent at an extension of 6000 microinches per inch. The relationship was most efficient in the region of the threshold of set, with the poorest correlations occurring at extension levels above the threshold region. It is possible that creep, specific gravity, and maximum strain are related only at initial extensions in or below the region of the threshold of set. This may well be if, as mentioned previously, the creep of some species increases exponentially above the threshold of set, while the creep of others increases hyperbolically.

It was found that, when the creep index was based on strain level (expressed as a percentage of maximum strain), larger correlation coefficients were obtained from the weighted index—maximum strain exponential regressions than when the index was based on a constant extension. This should not be interpreted to mean that the percentage strain level approach removes more real variation in creep between species than does the constant extension approach. The main feature of the strain level approach is that the initial extension used to calculate the creep index varies with each species, and depends upon its maximum strain. Thus, even though there was no correlation between creep at a given initial extension and maximum strain, a significant relationship could exist between creep at a given percent strain level and maximum strain simply because the creep of all species increases as initial strain increases.

The interaction of creep, specific gravity, initial extension, and maximum strain is summarized in Table 8 and illustrated in Fig. 9. The initial extension curves in Fig. 9 were constructed by connecting points of equal strain on the strain level curves. This indirect method of determining the initial extension curves was deemed slightly more reliable (for example at large maximum strains) than using the fitted equations directly because experimental data at the higher initial extensions were not available for some of the species.

Fig. 9 shows that creep is favored by low specific gravity and high maximum strain. The relationship between these variables is explained by considering specific gravity as a measure of cell wall spacing, and maximum strain as a partial measure of the lateral order, or degree of crystallinity, of the cellulose chain molecules.

The interpretation given here to specific gravity is the usual one, namely, that it is a macroscopic measure of the amount of cell wall substance contained in a unit volume. Considering maximum strain to be correlated with degree of crystallinity is not without precedent. Ward (41) found that the maximum elongation of cotton yarns increased with decreased crystallinity. Similar results are reported by Ingersoll (14) for viscose rayons. It is generally accepted by high-polymer theorists that extensibility and lateral order are functionally related (5, 10, 13, 27).

Since creep is attributed to the straightening of chain segments in the more disordered regions of the fibers, it follows that creep is favored by local molecular disorder. Creep and maximum strain would seem to be related, therefore, because of their mutual relationship with crystallinity.

The Stress—Strain Relationship from the Static Test to Failure: An important concern of this research work was to determine how accurately Hooke's Law describes the mechanical behavior of wood, and to determine the significance that should be given to points such as the proportional limit and the lower limit of plastic flow.

The load—strain relationship of a red oak specimen tested to failure in tension is shown in Fig. 10. This figure also shows the relationship between load and the differences between successive strain measurements for the same specimen.

By comparing the two relationships shown in Fig. 10, it can be seen that stress and strain are not precisely proportional. If these quantities were proportional, truly Hookean behavior, differences between successive strain measurements would be constant up to the proportional limit. The non-proportional increase in strain relative to the increase in stress, however, is so small that it does not significantly affect the essential linearity of the coarsely-measured load-strain relationship. This is in agreement with the resuts of the short-term creep tests, which show that creep occurs at the very lowest stress levels, but, in short periods of time, is small compared to total extension. Initial strain, the larger portion of the total strain, was found in general to be fully recoverable and therefore elastic in nature.

The proportional limit shown in Fig. 10 was determined visually, as is the normal practice, and is that point at which total strain apparently ceases to be proportional to load. The lower limit of plastic flow shown was also determined visually, and as defined by Ivanov, is at load (stress) at which the differences between successive strain measurements increase more than in proportion to the increase in load.

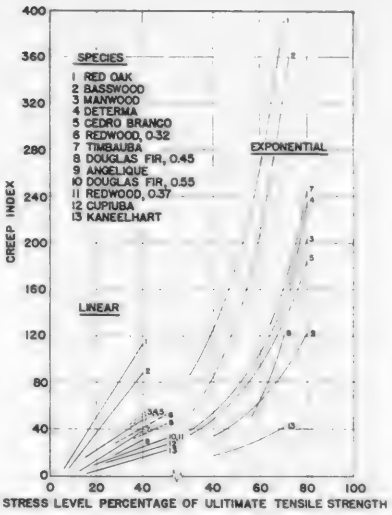

Fig. 8.—Comparison of the linear and exponential creep index—stress level regressions of the eleven species investigated.

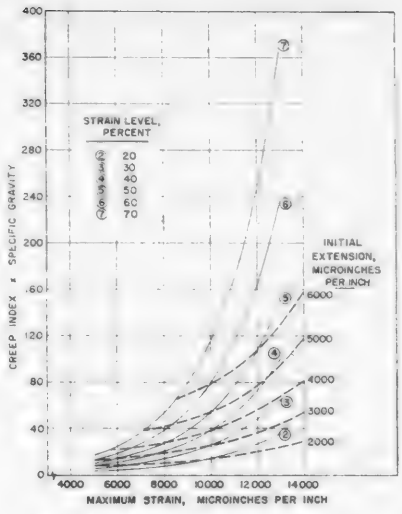

Fig. 9—The relationship between creep index times specific gravity and maximum strain at six strain levels and five initial extensions.

The proportional limit load and the load characterizing the lower limit of plastic flow are very nearly the same for this particular red oak specimen tested in tension parallel to the grain. A comparison of lower limit of plastic flow values reported by Ivanov (15) for compression parallel to the grain and static bending with corresponding proportional limit stresses reported by Markwardt and Wilson (29) indicates that these two limits occur in the same general stress-level region.

On the basis of the multiple-cycle creep tests, it is evident that the proportional limit and the lower limit of plastic flow are not associated with any load or initial strain that characterizes a threshold of failure or of flow. Specimens that were tested at successively higher stress levels and that were not permitted to recover betwen cycles[6] exhibited no such yield point, other than a threshold of set. The average initial strain at which set first begins is approximately 4000 microinches per inch. This initial extension is associated with a load approximately one-half that of the proportional limit and lower limit of plastic flow of the oak specimen of Fig. 10.

The statement that the two limits have no important significance with regard to a threshold of failure or flow is borne out by the results of other investigations (6, 16, 26, 39), which have shown that both these limits vary with the rate of loading. What undoubtedly happens is that more creep occurs at the slower rates of loading, and thus produces evidence of a more pronounced deviation from proportionality at lower load levels in both cases.

It would seem that the most accurate description of the load—strain difference relationship would be one in which the strain differences are truly proportional to load up to the threshold of set, but above this point would increase more than proportionally to load. In other words, the relationship would be of the same type as that between creep and stress level. To illustrate the difference between this approach and Ivanov's method, linear regressions were fitted by the method of least squares to the load—strain difference data of the red oak specimen below the threshold of set and to the same data below the lower limit of plastic flow. The difference between the slopes of these two regressions is shown in Fig. 10. The indistinctness

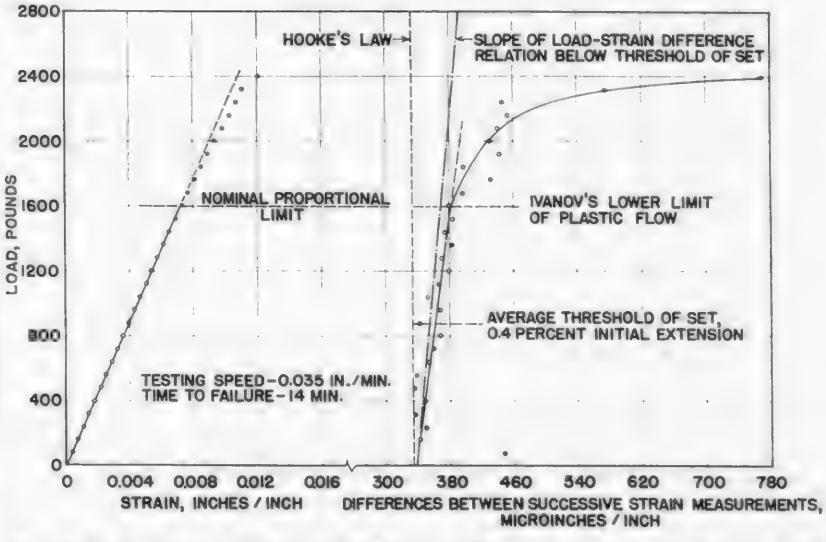
HOOKE'S LAW
SLOPE OF LOAD-STRAIN DIFFERENCE RELATION BELOW THRESHOLD OF SET
NOMINAL PROPORTIONAL LIMIT
IVANOV'S LOWER LIMIT OF PLASTIC FLOW
AVERAGE THRESHOLD OF SET, 0.4 PERCENT INITIAL EXTENSION
TESTING SPEED-0.035 IN./MIN.
TIME TO FAILURE-14 MIN.
LOAD, POUNDS
STRAIN, INCHES / INCH
DIFFERENCES BETWEEN SUCCESSIVE STRAIN MEASUREMENTS, MICROINCHES / INCH

Fig. 10—Load—strain and load—strain difference relationships for a red oak specimen tested statically to failure.

[6] This type of loading procedure approximates that used in a static test to failure.

of the threshold of set in the load—strain difference data of this figure is attributed to the small amount of creep that is occurring and the poor accurracy that results when loads and strains, are measured during loading. These factors tend to obscure the transition from the linear to the curvilinear relation and make it reasonable, without evidence to the contrary, to extend the linear regression up to higher loads.

It is obvious from Fig. 10 that the modulus of elasticity calculated on the basis of the slope of the load—total strain relationship is somewhat lower than the true value because of the creep that has occurred during loading. An estimate of the true modulus can be determined by assuming that the zero-load intercept of the load—strain differences relationship below the threshold of set is that portion of the total strain which is immediately elastic and which occurs for each constant increment of load. This assumption is valid, for it has been shown that initial strain tends to be fully recoverable.

The zero-load intercept for the oak specimen of Fig. 10 is 338 microinches per inch, and is associated with a load increment of 80 pounds. The calculated load—strain modulus (equivalent to the true modulus of elasticity) of $80/338 \times 10^{-6}$ is approximately 4½ percent greater than the modulus based on the total srain between 400 and 800 pounds; 5½ percent greater than the modulus based on the total strain between 400 and 1200 pounds; and 8 percent greater than the modulus based cn the total strain between 400 and 1600 pounds. The increasing error is a result of the cumulative effect of creep that is occurring above the 400-pound base strain. It is quite possible that the difference between the modulus of elasticity of wood as determined by dynamic methods and that determined from static tests to failure can be attributed to creep behavior.

Summary and Conclusions

From the results of short-term creep tests on 11 species of wood at room temperatures and 12 percent moisture content, the following conclusions have been drawn concerning the time-dependent strain behavior of wood in tension parallel to the grain:

(a) Creep is proportional to the logarithm of time at all load levels for the first 30 to 40 minutes of the sustained-load period. At longer times, creep tends to increase more than proportionally with logarithm of time.

(b) Measurable creep occurs in all species at stress levels at least of low as 15 percent of the short-time strength. Some species exhibit creep at the 5 percent stress level.

(c) Set begins to occur at about the same initial extension region for all species. The average threshold of set occurs at an initial extension of approximately 0.4 percent. Immediate or initial strain is fully elastic.

(d) The creep—initial strain and creep—stress level relations are characterized by a two-stage relationship consisting of a linear regression up to the threshold of set and a curvilinear regression thereafter. All species exhibit this type of behavior.

(e) A large percentage of the difference between species with regard to magnitude of the creep response in and below the region of the threshold of set can be accounted for by differences in specific gravity and maximum tensile strain. Species of low density and high extensibility creep more than species with a high specific gravity but low extensibility.

Further, the results of this study indicate that the stress—strain relationship of wood in a static test to failure is not linear in any region where creep occurs. The reason that stress and strain appear to be proportional when normal test methods are used is because the creep that occurs in the relatively short loading time is small relative to the total strain response, while the major portion is immediately elastic and proportional to stress. As loading is continued, a point is reached where the creep contribution becomes significantly large and causes the stress—strain relation to exhibit an apparent proportional limit, a point where strain, as ordinarily measured in static testing, appears to increase—at a faster rate than the increase in load.

The smaller the magnitude of the creep response and the faster the rate of loading, the more closely will the behavior approach that of Hooke's Law. Although the behavior of wood under load is not strictly Hookean, little error results from assuming, for practical purposes, that stress and strain are proportional at the lower load levels in a static test to failure.

The nominal proportional limit and Ivanov's lower limit of plastic flow appear to have no direct significance with regard to a stress or strain level region at which either set, flow, or failure is initiated in wood. Although these limits are quantities that depend upon creep rate, and therefore vary with rate of loading, they do provide approximate measures of the creep behavior of different species. At a constant rate of loading, those species which have a low proportional limit, or low limit of plastic flow, relative to the short-term maximum stress, obviously creep more than those species with higher such limits.

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Abstracting the Literature

MICROBIOLOGY

McNeel, W., Jr. (Central Michigan Univ.) Shenefelt, R. D. (Wisconsin Univ.), Pascoe, T. A. (Nekoosa–Edwards Paper Co.), and Scheffer, T. C. (U.S. Forest Prods. Lab.) Effect of a decay producing organism, *Peniophora gigantea* (Fr). Massee, on quality of pulp from jack pine. Tappi 43, no. 4: 323–9 (April, 1960).

A study designed to measure losses by insects attacking jack pine pulpwood in central Wisconsin is described. Direct measurements of wood losses caused by insect activity were obtained, but it was extremely difficult to measure their influence on pulp quality. It was found, however, that the amt. of wood decay, caused almost entirely by the wood rotting organism *Peniophora gigantea* (Fr.) Massee, and the amt. of blue stain were considerably less in pulpwood where insects were controlled. This association between insect abundance and amts. of *P. gigantea* led the investigators to det. the effect of this wood rotter on pulp quality. Increases in the percentage of decay in pulpwood caused significant decreases in burst, tear, tensile strength, caliper, opacity, and probably folding endurance of pulp. A slight increase in pulp yields during storage was very probably due to the type action of *P. gigantea* on wood components. Pulpwood, and consequently pulp, is variously affected during storage depending on the conditions that favor or retard fungus growth. A measurement of decay is a far better estimate of the quality of pulp than other criteria such as length of storage. By detg. the amt. of decay in jack pine logs, it is possible to estimate the value of the pulp obtained. 19 ref. (A.B.I.P.C. 30:12)

Wilson, Louis F. Reducing pulpwood losses from borer attacks by shading conventional pulp piles. U.S. Forest Serv., Lake States Forest Expt. Sta., Tech. Notes No. 583. St. Paul, Minn., The Station, 1960. 2 p.

Pulpwood sticks of spruce and balsam fir were stacked in various ways in order to compare the damage done by wood borers (in this case, primarily the white-spotted sawyer). The comparison indicated that, to reduce the borer attacks, the pulpwood should be piled in std. piles under the shade of standing trees if other conventional preventive measures cannot be taken. In the absence of shading trees, as when clear cutting is practiced, fresh boughs should be laid over the pile. Spring- or summer-cut wood, piled in the forest should be removed before the flg. spring, otherwise wood-infesting fungi become important. (A.B.I.P.C. 30:12)

GENETICS

Mergen, Francois. (Yale Univ. School of Forestry). Forest tree breeding research. Unasylva 13, no. 2: 81–8; no. 3: 129–37 (1959).

Forest tree breeding is still in the early stages of devt.—in the descriptive phase of the forming process. During the past few decades, considerable knowledge has been gained on the genetic variability within tree species, on their physiology, on how to test the inherent variability, and on how to use this information advantageously in silviculture. Research carried out in areas of tree selection, progeny and clonal tests, and vegetative propagation, natural hybridization, controlled hybridization, controlled pollination methods, and flower and fruit induction is revd. More work, both basic and applied, is necessary to advance the field of forest tree breeding; during this period and as new information is obtained, many current ideas on tree selection and progeny testing will be modified and changed. 30 ref. (A.B.I.P.C. 30:10)

Northcott, P. L. Is spiral grain the normal growth pattern? Forestry Chronicle 33, no. 4: 335–52 (Dec., 1957).

A report is given on the occurrence of spiral grain in trees. Spiral grain appears to be indep. of the complexity of the wood structure, having been recorded both in gymnosperms and angiosperms. Each species appears to have its own charac. pattern of spiral growth, although the nature of the spiral varies widely from tree to tree. Spiral grain was present in 99.6% of the 594 mature trees inspected. No claim is made that proof is presented that spiral grain is the normal growth pattern, but all of the data reptd. support this view. A so-called "straight-grain" tree is probably just passing through zero spiral from left to right or vice versa. 51 ref. (A.B.I.P.C. 30:12)

FUNDAMENTAL PROPERTIES

Roelofsen, Pieter A. The plant cell-wall [Encyclopedia of plant anatomy. Vol. 3, Part 4] Berlin-Nikolassee, Gebrüder Borntraeger, 2d ed. 1959. 335 p. + 68 plates. [Engl.]

Review

The first edition of this volume in 1925, which was written by C. van Wisselingh, attempted to treat the subject matter quite completely. Since then, however, a tremendous amount of research has been contributed to elucidate the structure and the chemical and physical properties of the plant cell wall. Professor Roelofsen (Inst. of Technol. of Delft) has, therefore, wisely confined himself to a sketch of the present state of our knowledge, with special emphasis on those aspects of interest to the botanist. With a good balance of subject matter, numerous literature references, and profuse, well chosen, and nicely executed illustrations, he has done an excellent job.

The first part (approx. one third) of the book is devoted to the chemical and physical nature of cellulose, chitin, hemicelluloses, water-soluble polyoses, polyuronides, lignin, lipid-like substances (cutin, suberin, sporopollenin, and wax), proteins, extractive materials, phytomelane, and inorganic substances. If some of these terms seem strange to the pulp and paper chemist, it must be remembered that plant tissues other than wood have been included by the author. The discussion of cellulose occupies about one third of the space, but obviously only brief reference could be made to it and the other substances listed, since consideration of their nature has filled numerous volumes.

The second part (*ca.* two thirds) of the book deals with the cell wall structure. There is a very good coverage of the latest concepts of the primary and secondary walls of various fibers and other cells as elucidated by special methods of investigation, such as polarization microscopy, x-ray diffraction techniques, and electron microscopy. The collection of the details of cell-wall research, particularly those of the last 35 years, is the outstanding contribution of this volume. [A.B.I.P.C. 30:9]

I. H. Isenberg

Paul, Benson H. (U. S. Forest Prods. Lab.) The juvenile core in conifers. Tappi 43, no. 1: 1–2 (Jan., 1960).

Juvenile wood comprises wide-ringed, low-d. matl. of high longitudinal shrinkage near the pith. Narrow-ringed wood of the same species lacks these undesirable characs. Thus trees originating in closely stocked stands contain only negligible amts. of juvenile wood. The no. of juvenile growth rings appears to be related to the size and position of the green crown. Thus its amt. is subject to control by regulated stocking in forest management. 6 ref. [A.B.I.P.C. 30:9]

Hamilton, J. Certain wood properties of southern red oak *(Quercus falcata Michx.)* in relation to location within the bole and to environment. Ph.D. Thesis. North Carolina State Col., 1960. 243 p. [Microfilm] Dissertation Abstr. 20, no. 11:4231–2 (May, 1960).

Six southern red oak trees were subjected to intensive lab. anal. in order to det. how 16 wood props. varied within the boles of individual trees and to det. the effect of environment on these props. Some of the data derived are discussed. The wood props. examd. included phys. props. such as sp. gr. and ring width, mech. props. such as side hardness, and anatomical characs. such as fiber length and fiber tracheid length. (A.B.I.P.C. 31:1)

Kauman, W. G. Contribution to the theory of cell collapse in wood: Investigations with *Eucalyptus regnans*. Australian J. Appl. Sci. 2, no. 3:122–45 (March 1960).

Total collapse is considered as the sum of "liquid tension collapse" and "stress collapse." An equation is derived giving total collapse as a linear function of wood temp. and, to a smaller extent, of collapse-free shrinkage. The parameters of the equation depend only on surface tension data and on structural rheological props. of the wood. To test the theory, *Eucalyptus regnans* cubes of 7/8 in. edge length were dried at temps. ranging from 70 to 285° F., using two levels of humidity at each temp. In addn., specimens measuring 7/8 by 7/8 by 3 in. were dried at 150° F. and low humidity. The results show good agreement with theoret. values for wood temps. up to about 190° F. For higher temps. or very low humidities, collapse is found to be significantly time-dependent. Collapse in small, end-sealed cubes is shown to be of the same order as that in the thickness of boards of rectangular cross section, but the latter collapse less in width. 20 ref. (A.B.I.P.C. 31:1)

Sandermann, Wilhelm, and Rothkamm, Martin. On the determination and practical importance of the pH values of commercial timbers. Holz Roh- u. Werkstoff 17, no. 11; 433–40 (Nov., 1959). [Ger.; Engl. sum.]

The pH of wood is important not only for research work but also for pract. applns., since it is related to the corrosivity, gluability, and paintability of com. timber; to the wood-tannin reaction and other discolorations; and to fungal decay and preservative fixation. The pH of wood also plays a significant role in pulp, paper, and particle-board mfr. Among various available methods of pH detn. in wood, that of Campbell and Bryant [Nature 147: 357 (1941)] was found to be the most pract. It was appl. to det. the pH and buffering capacity of *ca.* 80 com. timbers (aq. suspensions of wood powders), using a universal pH-meter with a glass electrode. Differences between sapwood and heartwood and the effects of trunk height and felling time were also studied. Tests with surface and incision electrodes gave some useful results, provided the wood moisture was above the fiber-satn. point. 42 ref. [A.B.I.P.C. 30: 7]

LIGHT WOOD OILS

Filippov, B. N. The chemical composition of the light wood oils from the Amzinsk plant. Gidroliz. i Lesokhim. Prom. 12, no. 4: 22–3 (1959). [Russ.]

At the Amzinsk wood distn. plant, where birchwood is pyrolyzed under rel. mild conditions, the light oil fraction, which floats on the surface of pyroligneous acid after methanol had been removed, is obtained in a yield of 2.5 kg./cu. m. wood. The light oil fraction was analyzed by fractional distn. and selective solvent extn., and was found to contain 76% hydrocarbons boiling at 150–325° C., 2.9% neut. substances (alcs., esters, ketones, and aldehydes) boiling at about 280°, 10–13% phenols (mainly pyrocatechol and resorcinol) boiling at 258°, and 1.2% nonvolatile fatty acids. About 8–10% of the hydrocarbons occurred in the form of suspended solid particles, which could be sepd. by filtration under reduced pressure. The solid hydrocarbon fraction had a b.p. above 290° and props. similar to the paraffin fraction of petroleum. The light oils from wood distn. can be used as a substitute for coal tar oils in many branches of ind. (A.B.I.P.C. 31:4)

WOOD RESIN CONTAINERS

Nysenko, N. T., and Nysenko, L. A. Containers for wood resin, made of wood-derived plastic material. Gidroliz. i Lesokhim. Prom. 12, no 4: 14 (1959). [Russ.]

The metallic receiving containers used in tree tapping can be replaced with noncorroding containers molded under pressure from a mixt. of sawdust, wood-gasification tar, and a small amt. of phenol or PF resin. The binding resin is prepd. either by mixing a soln. of oxidized wood tar with a PF soln. or by condensing wood tar with formaldehyde and phenol in an alk. medium. The containers absorb a max. of 7–10% moisture and are resistant to tapping chemicals and to changing weather conditions. Turpentine stored in these containers does not darken. (A.B.I.P.C. 31:4)

RADIOACTIVE TRACERS

Jenssen, W., Fogelberg, B. C., and Johanson, M. Studies on the possibilities of using radioactive tracers to follow the penetration of cooking liquors into wood. Paperi ja Puu 42, no. 7: 393–400 (July, 1960). [Engl.: Finn. sum.]

After a brief survey of different techniques which have so far been used to investigate the process of wood impregnation, some expts. are described in which the penetration of a calcium-base sulfite cooking liquor contg. radioactive calcium into spruce sapwood as a function of temp., time, and pressure was studied by means of autoradiography and measurements of activity. Measurements of radioactivity were made on slices cut from the chips with a microtome, and autoradiographs of them were taken and scanned by means of a recording photometer. Tracer techniques can be used with advantage for a detailed study of penetration, esp. as regards heterogeneities. 24 ref. (A.B.I.P.C. 31:5)

NAMES in the NEWS

The Society of American Foresters has selected **Edward C. Stone,** associate professor of forestry, and **John A. Zivnuska,** professor of forestry, University of California, Berkeley, to participate in its national visiting scientists program. The program, financed by the NSF and sponsored by the Society of American Foresters, seeks to stimulate interest in forestry as a career.

R. P. McCulloch, president and board chairman of the McCulloch Corporation, announced that **George Eichelsbach, Jr.,** former vice president and general manager for the Los Angeles division has been promoted to executive vice president for the entire corporation.

Edward Sucoff has joined the staff of the University of Minnesota School of Forestry as an assistant professor. Mr. Sucoff was formerly with Northeastern Forest Experiment Station, Laurel, Md.

Clarence A. Swords, president of the Swords–Morton Veneer and Lumber Company, Rock Island, Ill., was installed as president of the American Walnut Manufacturers Association at its annual January meeting. **G. C. Romeiser** was re-elected secretary–manager; **G. W. Hartzell,** vice-president of Hartzell Industries, Piqua, O., became vice-president; and **E. E. Freeman, Jr.,** president of the George E. Tomlinson Co., Winchester, Ky., became treasurer.

William G. Van Beckum has been elected to the new position of vice president for research and development for The Pacific Lumber Company. He will have administrative responsibility for the research and development program, development engineering, new product and business development, and by-product program.

James B. Edens, president of Southwest Forest Industries, Inc., has announced the appointment of **H. L. Fates** as vice president in charge of finance and the election of **R. W. Rehfeld** as vice president and treasurer.

The Forest Genetics Research Foundation, Berkeley, Calif., announced the election of **Richard A. Colgan, Jr.,** as president. Mr. Colgan is general manager of the Shasta Forests Company, Redding, Calif.

Ray Heizer has been appointed general sales manager for Gisholt Plastics of Madison, Wis. Previously, he served as an R & D engineer and as a chief engineer in the molding of reinforced plastics.

Wilco Machine Works, Inc., Memphis, Tenn., announces the recent appointment of **A. C. Tilman** as manager of their new eastern sales office, Winston-Salem, N. C.

The promotion of **Harvey H. Warnaca** from insulating board products sales manager to general sales manager of Simpson Timber Company, Seattle, Wash., has been announced. Mr. Warnaca has been with Simpson since 1949.

F. H. Werling, vice-president of Kimberly-Clark Corp., Neenah, Wis., has been named chairman of the Wisconsin Committee of American Forest Products Industries for 1961.

An organic chemist, **Dr. Bela Balough,** has been named to conduct research on redwood at the University of California's Forest Products Laboratory, Richmond, Dr. Balough escaped from Budapest to Vienna, Austria, during the Hungarian revolution, 1956. CFPL director **F. E. Dickinson** stated that the post-doctoral appointment was provided by a great-in-aid from the California Redwood Association.

A. R. Marusi, president of The Borden Chemical Company has announced the formation of a new international division and the appointment of **John J. O'Connor** as senior vice president to head it. The move to division status for international operations has been necessitated by the expansion of Borden's overseas companies. Mr. O'Connor served as vice president of what formerly was the international department.

Dr. E. C. Jahn and **Dr. Vivian T. Stannett,** State University College of Forestry, Syracuse University, are co-authors of a chapter, "Polymer Modified Papers," for a series of engineering books entitled *Modern Materials,* publish by Academic Press, Inc.

The National Academy of Sciences—National Research Council, announced recently the appointment of **Dr. R. P. Whitney,** Institute of Paper Chemistry, Appleton, Wis., as Chairman of the Academy–Research Council's Committee on Paper Base Materials.

J. H. Dieterich, forest fire research specialist, has been appointed to the staff of the U. S. Lake States Forest Experiment Station to head up the fire research program of the Station, according to **M. B. Dickerman,** director. In his new position, Mr. Dieterich will be conducting research in the effects of microclimate, fuel type, and fuel concentration on fire behavior.

E. L. Quirk, executive vice president of Southwest Forest Industries, Inc., Phoenix, Ariz., recently reported new assignments. **B. C. (Carney) Denvir,** has been elected a vice president and will head up the Marketing Division of the recently created Wood Products Group, **Henry O'B Mehen,** will be director of the Eastern Region; and **J. H. Bruce** will be director of Western Region sales.

Robert N. Colwell, internationally-renowned authority on photo interpretation from the University of California's School of Forestry, was honored for his outstanding contributions to this field at the recent quadrennial World Congress of the International Society of Photogrammetry in London.

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E-414—Flakeboard Technical Service Representative: two positions—one in Midwest, one in California, in marketing program of new flakeboard plant. Wood Technology degree required, and practical experience in flakeboard or allied industry desirable. Submit resume to L. L. Oliver, Collins Pine Co.,

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627—**Wood-finishing and production specialist.** Bachelor degree in wood technology. Solid research and development background. Ten years experience with nationally known producers of quality products. Developed complete specifications followed through on inspection and quality control, production, trouble shooting, etc. Designed and installed fully conveyorized layouts. Thoroughly familiar with all phases—yard through finished products. (March)

628—Capable of operating & maintaining machinery, and have completed a course in Heavy Duty Equipment Maintenance. Also completed a course in Conservation. Has agricultural background. (March)

634—Lumber seasoning consultant, research, kiln operator, varied lumber mill; totalling 11½ yrs. experience. Wood Products B.S. 1949 Oregon State College. Seeks position in seasoning, production, quality control. West. (March)

635—Plant manager or engineering position wanted; 18 yrs. experience in plant managment, engineering, estimating purchasing, quality control, good in methods and costs. B.S. degree. (March)

636—Graduate wood technologist available in June, with M.S. Studied wood preservation, wood seasoning, bonding of wood, finishes, timber physics, and wood anatomy, 29 years old, married 1 child, military obligation. Prefers Northeast, Carolinas; Chesapeake, Ohio Valley and Great Lakes regions.

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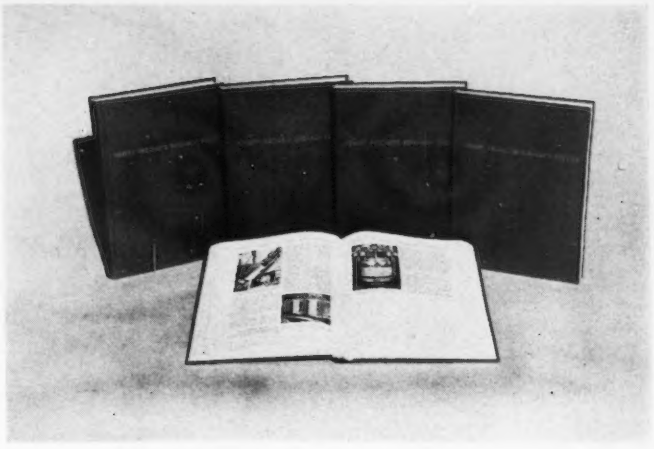

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Articles cover: economics of wood-waste utilization; losses in Redwood logging; small log gang sawmill; utilization of low-grade hardwood lumber; wood-distillation industry; sawdust carbonization; animal feeds from wood residue; small wood briquetting machine; special machines for utilization of waste slabs for glued core stock; interior trim from wood waste; wood-fiber production with revolving disk mills; effect of some manufacturing variables on the properties of fiberboard prepared from milled Douglas-Fir; small hydraulic log barker; mechanical methods of bark removal; studies on the chemical composition of bark and its utilization for structural boards; research in industry laboratories; history of furniture finishes; finishes resistant to alcohols and acids; low-bake synthetic finishes; simple testing methods for finishers; planning floor space for woodworking equipment; maintenance and operating practice for tungsten carbide tools.

1949—Vol. III—RAW MATERIAL, FURNITURE, PLYWOOD, UTILIZATION, GLUES, SEASONING. 55 papers, 607 pp.

Articles cover: more wood per acre; integrated wood utilization at Crossett; harvesting sawlogs; portable wood chippers; wood fibers from veneer waste; small permanent-type sawmills in better forest utilizatiton; pulpwood handling in the Lake States; tropical wood research for the furniture industry; effect of plywood glue lines on the accuracy of moisture-meter indications; No. 3 common Northern hardwood lumber for mechanized processing into glued products; cut stock from western softwoods; assembly material in furniture manufacture; supplementing wood with metal in furniture manufacturing; extending hot press urea resin with wheat and rye flour; furniture finishes; lumber core panels; rotary veneer cutting; molding plywood; insert-point circular headsaws; ills besetting the furniture industry; utilization of Redwood bark; utilization of waste sulfite liquor in concrete; semichemical pulping; dry-formed boards bonded with resins; wood, plywood and hardboard; compreg-resin-treated densified wood; wood preservatives; wood boring beetles; ignition temperatures of fireproofed wood, untreated sound wood, and untreated decayed wood; wood waste disposal and air pollution control in the Los Angeles area; pulp mill pollution; chemical composition of Ponderosa and Sugar Pine barks; lumber recovery from Douglas-Fir logs in British Columbia; resin adhesives; development of working stresses for stress-grade lumber; design and performance of laminated wood trusses, glued laminated wood, glued laminated Wej-weld frames; radio frequency heating.

1950—Vol. IV—MILLING, CONTAINERS, QUALITY CONTROL, PLYWOOD. 45 papers, 506 pp.

Articles cover: quality of second growth Douglas Fir; grading problems; quality control and the improved seasoning processes of the Redwood industry; saw teeth in action; lumber research to meet modern competition; hardwood log grading; recent developments in wirebound containers; method of utilizing and fabricating waste lumber; tests of strapped and lightweight lettuce crates; recent developments in containers; papermaking fibrous raw materials; utilization of low-grade hardwoods and softwoods; relation between wood and pulp properties; power vs. hand falling and bucking in logging operations; handling pulpwood; quality control in sawmill operations; hardwood plywood quality control; quality control in furniture production; defect detection equpiment non-destructive testing.

1951—Vol. V—MILLING, MACHINING, PRESERVATION, UTILIZATION, GLUES, KILN DRYING. 51 papers, 400 pp.

Articles cover: circular sawmills in the Tennessee Valley region; quality control in lumber manufacture, gangsaws in the manufacture of southern pine lumber; tropical hardwood production, logging and military equipment availability; defense and the availability of woodworking equipment; the importance of wood in the mobilization program; mobilization requirements for technical men in the woodworking industry; lumber conservation in military procurement and container design; military requirements for wood in packaging; wood requirements for specialized military uses; the place of small business in the military procurement program; marine laminating; selecting White Oak for bending lumber; machinability studies; carbide cutting tools in the wood industry; carbides; fire retardant treated lumber; wood preservation with particular reference to creosote; what the furniture industry expects from college-trained men; the scope and objectives of college training; graduate training in forest products technology.

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3 All members of the Forest Products Research Society and the Wood Products Industry are invited to submit names of individuals to be considered by the Board of Judges for the Award. All entries, in duplicate, must be submitted to the Executive Secretary of the Forest Products Research Society, 417 North Walnut Street, Madison 5, Wisconsin. All entries must be received by May 1 to be eligible for the 1961 Award.

4 Entries should be approximately 300 words in length, and should not exceed 350 words, should include name and address of person submitting the entry, name and address of the proposed Award recipient, his occupation or employment, a review of the nature of work of the individual, purpose, accomplishments, and results. Entries may be documented with supporting material.

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Duke University
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